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STONE CHARACTERISTICS AND THEIR RELATION TO TRICKLING FILTER PONDING STUDIES

Purdue University
Lafayette, Indiana

20 May 1962

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STONE CHARACTERISTICS
AND
THEIR RELATION TO
TRICKLING FILTER PONDING

Purdue University

Lafayette, Indiana

Sponsors

Indiana Stream Pollution Control Board

and the

Department of Health, Education and Welfare

Public Health Service

May 20, 1962

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B. A. Poole, Technical Secretary
Indiana Stream Pollution Control Board
1330 West Michigan Street
Indianapolis 7, Indiana

Dear Mr. Poole:

Submitted herewith is a detailed report of the research done at Purdue University by Otto Kroboth, under the direction of Professor Don E. Bloodgood, on trickling filter stone characteristics and their relation to trickling filter ponding.

Sponsorship by the Stream Pollution Control Board of the State of Indiana was provided in accordance with a Memorandum of Agreement made May 15, 1960, and supplemented June 23, 1961. Funds were from said Board's allotment under Public Law 660, the Federal Water Pollution Control law.

Yours very truly,

Don E. Bloodgood
Professor of
Sanitary Engineering

DEB:sb

ABSTRACT

This study was initiated in an attempt to obtain some information on the behavior of trickling filter stones during and after placement in the filter bed in relation to the clogging of the filters.

A survey of the literature available on trickling filter media, indicates that most of the effort of other authors has been directed towards the investigation of the biological slime growth on the filter media. Throughout the review of literature it was observed that not much emphasis has been placed on the role of the trickling filter media in the clogging of the filters.

The standard Los Angeles abrasive test and a modified abrasive test were used to resemble the handling of the stone in the field. During the course of the study methods were developed to obtain the total volume of a sample, the volume of the voids in a sample, and a procedure for measuring the sizes of stones and void spaces.

The data obtained during this study indicates that:

1. The clogging of trickling filters may not be attributed to the stone if it meets the present standards for stone quality.
2. The stone when subjected to an abrasive action did not produce enough fine material in a given volume of stone to materially decrease the void volume.
3. The amount of abraded material produced during the abrasive action is not indirect relation to the severity with which the stone is handled.
4. The size of the void spaces are not in a constant relation with the size of the stones.
5. If the stone is free of fines prior to the placement in a filter bed, it can very likely be placed with most any equipment available.

TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF FIGURES	ix
ABSTRACT	x
REVIEW OF LITERATURE	1
Introduction	1
Trickling Filter Media	1
Media Specifications	3
Type and Size	3
Shape	6
Durability	7
Placement of media	8
Ponding or Clogging of Filters	9
INTRODUCTION	11
DESCRIPTION OF APPARATUS	12
Introduction	12
Los Angeles Machine	12
Sieves	14
PART I BEHAVIOR OF TRICKLING FILTER STONES UNDER AN ABRASIVE ACTION	17
Introduction	17
Experimental Procedure	17
Stone Samples	17
Method of Testing	20
Presentation of Data	21
Test Results Using the Standard Los Angeles Test with Complete Sieve Analyses	21
Test Results Using the Standard Los Angeles Abrasive Test with Partial Sieve Analyses	22
Test Results Using the Modified Los Angeles Test with Complete Sieve Analyses	29
Test Results Using the Modified Los Angeles Test with Complete Sieve Analyses at Different Lengths of Time	29

Page

Effect of the Abrasive Charge on the Results of the Los Angeles Abrasive Test at 500 Revolutions 35
Consistency of the Results of the Los Angeles Test without Abrasive Charge 36
Discussion of Results 36
Comparison of the Results of the Los Angeles Test with Abrasive Charge at 500 Revolutions 36
Comparison of the Results of the Los Angeles Test without Abrasive Charge at 500 Revolutions 39
Effect of the Number of Revolutions on the Results of the Los Angeles Test without Abrasive Charge 54
Consistency of the Results of the Los Angeles Test with Abrasive Charge 57
Summary 60

PART II EFFECT OF THE ABRADED MATERIAL ON THE VOID SPACES 63

Introduction 63
Experimental Procedure 63
Determination of the Total Volume of Sample 63
Determination of the Volume of Void Spaces 65
Determination of the Sizes of Stone and Void Spaces 65
Determination of the Volume of Individual Fractions after the Los Angeles Abrasive Test 68
Presentation of Data 69
Test Results of Total Volume, Volume of Voids and Volume of Individual Fractions Determinations 69
Results of the Measurement of Stones and Void Spaces 82
Statistical Analyses of Data 94
Discussion and Summary of Data 101

FINAL SUMMARY 103

CONCLUSIONS 105

BIBLIOGRAPHY 106

APPENDIX A 109

APPENDIX B 114

APPENDIX C 116

APPENDIX D 119

LIST OF TABLES

TABLE		Page
I.	Federal Specification for Trickling Filters (Media Size) (34)	4
II.	Waseca, Minn., Specifications for Filter Stone (17) . . .	5
III.	Fort Worth Specifications for Filter Stone (17)	8
IV.	Fraction Size Range for the Material Retained on the Different Sieves Used in this Study	16
V.	Stone Samples Used in this Study	18
VI.	Sieve Analyses of the Material from Pfizer (New Stone) after the Abrasive Test	23
VII.	Sieve Analyses of the Material from Pfizer (Used Stone) after the Abrasive Test	24
VIII.	Sieve Analyses of the Material from Lebanon (Used Stone) after the Abrasive Test	25
IX.	Sieve Analyses of the Material from Frankfort (Used Stone) after the Abrasive Test	26
X.	Fractions of stone still retained on initial sieve size and material passing the #12 sieve after the Los Angeles test with abrasive charge at 500 revolutions	27
XI.	Sieve Analyses of Material from the Eli Lilly Waste Treatment Plant after the Los Angeles Test without the Abrasive Charge at 500 Revolutions	30
XII.	Sieve Analysis of Material from New Stone from Eli Lilly Waste Treatment Plant after the Los Angeles Test without Abrasive Charge at 500 Revolutions	31
XIII.	Sieve Analyses of Materila from the Eli Lilly Waste Treatment Plant after the Los Angeles Test without the Abrasive Charge at 500 Revolutions	32
XIV.	Sieve Analyses of Material from the Eli Lilly Waste Treatment Plant after the Los Angeles Test without the Abrasive Charge at 500 Revolutions	33

LIST OF TABLES, cont.

XV. Sieve Analysis of Material from the Eli Lilly Waste Treatment Plant after the Abrasive Test without Abrasive Charge and at Different Lengths of Time 34

XVI. Results of the Sieve Analyses of a Stone Sample from the Eli Lilly Waste Treatment Plant after the Los Angeles Test with an Abrasive Charge at 500 Revolutions 35

XVII. Results of the Sieve Analyses on Duplicate Samples of Stone after the Los Angeles Test with Abrasive Charge at 500 Revolutions 37

XVIII. Tabulation of Loss in Weight and Amount of Pan Size Material for Samples with Similar Size of Stone 38

XIX. Tabulation of the Loss in Weight after the Los Angeles Test with Abrasive Charge at 500 Revolutions Equivalent to a Nominal Size of 2 Inches 42

XX. Tabulation of the Amount of Pan Size Material after the Los Angeles Test with Abrasive Charge at 500 Revolutions Equivalent to a Nominal Size of 2 Inches 43

XXI. Tabulation of the Loss in Weight and the Pan Size Material after the Los Angeles Test without Abrasive Charge at 500 Revolutions 45

XXII. Tabulation of the Loss in Weight of the Sample and the Pan Size Material after the Los Angeles Test at 500 Revolutions 48

XXIII. Tabulation of the Loss in Weight after the Los Angeles Tests Equivalent to a Nominal Size of 2 Inches When Tested without Abrasive Charge at 500 Revolutions 50

XXIV. Tabulation of the Amount of Pan Size Material after the Los Angeles Tests Equivalent to a Nominal Size of 2 Inches When Tested without Abrasive Charge at 500 Revolutions . . 52

XXV. Tabulation of the Loss in Weight and the Amount of Pan Size Material after the Los Angeles Test without Abrasive Charge. 55

XXVI. Tabulation of the Equivalent Values of the Loss in Weight and the Pan Size Material to a Nominal Initial Sizes of 2 Inches When Tested without Abrasive Charge at 100 Revolutions 58

XXVII. Summary of the Average Equivalent Percentages of Loss in Weight of the Nominal Initial Size When Tested without the Abrasive Charge at 100 Revolutions 61

LIST OF TABLES, cont.

XXVIII. Summary of the Average Equivalent Percentages of Pan Size Material of the Nominal Initial Size When Tested without the Abrasive Charge at 100 Revolutions 62

XXIX. Sample Calculations for the Dilumination of Total Volume of a Sample of Stone before Abrasion in the Los Angeles Testing Machine without Abrasive Charge at 500 Revolutions 64

XXX. Sample Calculations for the Total Volume of Void Spaces in a Sample of Stone 66

XXXI. Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions 70

XXXII. Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions 71

XXXIII. Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions 72

XXXIV. Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions 73

XXXV. Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions 74

XXXVI. Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions 75

XXXVII. Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions 76

XXXVIII. Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions 77

XXXIX. Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 3-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions 78

XL. Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 2½-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions 79

XLI. Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 2-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions 80

LIST OF TABLES, cont.

XLII. Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 1½-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions 81

XLIII. Dimensions of 3 Inch Stone and Void Spaces 83

XLIV. Dimensions of 2½ Inch Stone and Void Spaces 85

XLV. Dimensions of 2 Inch Stone and Void Spaces 90

XLVI. Dimensions of 1½ Inch Stone and Void Spaces 92

XLVII. Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 3½ Inch Stones and of the Void Spaces between the Stones 97

XLVIII. Tabulation of the Results of the Statistical Analysis of the Size of the Axis of 3 Inch Stone and the Void Spaces between the Stones 98

XLIX. Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 2½ Inch Stone and the Void Spaces between the Stone 99

L. Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 2 Inch Stone and the Void Spaces between the Stones 100

LI. Tabulation of the Total Volume of Sample, Total Volume of Voids and Total Volume of Small Material for Different Sizes of Stone after the Abrasive Test 102

LII. Experimental and Calculated Values of the Percentage of Loss in Weight with Respect to the Amount Lost at 500 Revolutions for Different Number of Revolutions 110

LIST OF FIGURES

FIGURE		Page
1.	Los Angeles Abrasion Testing Machine	14
2.	Relationship Between Stone Sizes and Loss in Weight after the Los Angeles Abrasive Test with Abrasive Charge at 500 revolutions	40
3.	Relationship between stone sizes and amount of pan size material after the Los Angeles Abrasive test with abrasive charge at 500 revolutions	41
4.	Relationship between sizes of stone and the loss in weight after the Los Angeles Test without an abrasive charge at 500 revolutions	46
5.	Relationship between the sizes of stone and the amount of pan size material after the Los Angeles Test without abrasive charge at 500 revolutions	47
6.	Relationship between the No. of revolutions and the pan size material and the loss in weight after the Los Angeles Test without abrasive charge	56
7.	Flow Diagram for the Computation of the Mean and Standard Deviation of N Numbers or Points	95
8.	Flow Diagram for the Computation of Mean, Standard Deviation and Correlation Coefficient of N Pairs of Numbers or Points.	96

REVIEW OF LITERATURE

Introduction

A review of the literature on trickling filters shows a great number of reports on the clogging or ponding of these filters, attributing it to different causes as organic and hydraulic loading, slime growth and filter media size.

It was also noted that after the studies made on filter media in England and the United States in the 30's, there have been only a few studies reported on this subject.

The review of literature that follows summarizes the findings of previous investigations on sizes, shape, durability and other characteristics of filter media. Also a summary of different specifications for selection and placement of the media is presented.

Trickling Filter Media

In 1889 the first biological filter for the treatment of sewage was constructed in the United States at the Lawrance Experiment Station. Whipple (9) describes the media used in these filters as gravel stones which were ".....so large that even the coarser suspended particles of the sewage were not removed."

Thousands of sewage treatment plants have been constructed where trickling filters are used as part of the treatment. In 1940 (17) there were 1,486 trickling filter plants in use. By 1945, the reported number of trickling filter plants increased to 1,581; by

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1957 the reported number of plants was 2,682. Since then the number of trickling filter plants has continued to increase, being used in many locations where biological treatment of the wastes is needed.

Since the days of the Lawrance filter studies, different materials have been used for media including crushed rock (usually trap rock), granitic rock, limestone, blast furnace slag, coal, brush, tile, etc. (3, 4, 5, 11, 18), and more recently plastic media.

Over the years there has been some disagreement on which type of media is best for biological filtration. Hommon (11) reports on the results of field investigation on trickling filters using crushed blast furnace slag concluding that it is a durable material since no harmful disintegration over the years was noticed, thus being a " . . . suitable and desirable aggregate for use in sewage filters."

Lamar (12) states that natural chert stream gravel is a suitable material for use in trickling filters since it is composed essentially of silica (SiO_2) and, therefore, is practically insoluble. Thus being resistant to weather changes and does not prevent the free passage of the sewage, eliminating therefore the "pooling" or ponding of the filter.

Egan and Sandlin (19) state that plastic media has some advantages over the conventional crushed rock since it is more durable and provides a greater surface area to volume ratio.

Despite these claims, it appears that crushed rock is still the most commonly used material. An incomplete survey of trickling filters in the United States(15) shows that "...83% of the filter media in the plants included, was crushed rock of one type or another, 2% gravel, 11% slag and the remaining 4% of different other materials."

Media Specifications

Type and Size

Media specifications (20) do not include type of material; generally they state that the media used should be round, hard, clean and free of dust, and insoluble in sewage.

Kriege (33) states that the characteristics most commonly specified and tested for in mineral aggregates are hardness, toughness, abrasion, absorption, weight per cubic foot and roundness. Therefore, it is natural that these same specifications and test procedures should be called upon to dilumine the suitability of media for trickling filters. "Some questions may be raised, however, as to the advisability of this plan since it may lead to a false conception of what constitutes the best material for this specific purpose. It is perhaps advisable that as much thought be given to color, uniformity, crystalinity, fracture, cleavage, and the screen analysis with the percentage of voids of aggregates in the selection of the material."

The British Standard specifications (16) make no reccommendations as to size or type of media; the properties dealt with are uniformity of size, shape, freedom from dust and impurities, and durability.

There is a difference in opinions regarding the optimum media size. The Federal Specifications SS-C-744a for trickling filter media (34) state: "The filter media shall be as uniform in size as possible and, when tested with standard laboratory sieves having square openings, shall conform to the gradings shown in the table."

Table I

Federal Specification for Trickling Filters (Media Size) (34)

Sieve Size sq. openings in inches	amount passing sieve (% by weight)		
	3½-2½ inches	3½-2 inches	3-2 inches
4	100	100	100
3½	90-100	90-100	100
3	---	---	90-100
2½	0-10	---	---
2	0-2	0-10	0-10
1½	---	0-2	0-2

The "Recommended Standards for Sewage Works" (Ten States Standards) (21) recommended the following sizes:

1. - Mechanically graded over vibrating screen with square openings:

Passing 4½" screen	-	100% by weight
Retained 3" screen	-	95-100% by weight
Passing 2" screen	-	0- 2% by weight
Passing 1" screen	-	0- 1% by weight

2. - Hand picked field stone:

Maximum dimension of stone--5 inches
Minimum dimension of stone--3 inches

Furthermore, the specifications used for filter media at Waseca, Minn., (17) are presented in Table II showing that at least 95 percent of the stones had to pass the 4 inch sieve and that not less than 95 percent of the stone should be retained on the 2½ inch sieve while not more than 1 percent should pass the 2 inch sieve.

Table II

Waseca, Minn., Specifications for Filter Stone (17)

Passing 4-inch mesh, at least	95 percent
Retained on 3 inch mesh	45 to 65 percent
Retained on 2½ inch mesh, not less than	95 percent
Passing 2 inch mesh, not more than	1 percent

The disagreement among the different authors seems to be on the effect of the size on the surface area, the clogging tendency of some filters by accumulation of slime in the void spaces, etc.

Goldthorpe (1) is of the opinion that the media should have "... a high surface area to weight ratio, and contain and maintain a large percentage of voids to allow the passage of air in excess of the demands of the bed." Thus he implies that the smaller the material the greater the surface area per unit volume while the percentage of voids remains constant.

Imhoff and Fair (5) state that "... the advantage of increased contact surface gained by decreased grain size...is offset to some extent by the reduction in size of individual voids and consequently greater resistance to air flow and unloading."

Stanley (10) is of the same opinion as Parga (7), who observes that if the size of particles is large, the total area is small but if the material is to small, clogging will occur easily.

Rankin (8) corroborates the findings made by Goldthorpe, Stanley and Parga by stating that "Theoretically, the smaller the stone, the greater the surface area available for bacterial films, but practical considerations indicate that larger sizes, from 2½ to 3 inches (or even larger), are more satisfactory. A smaller size has greater

tendency toward ponding and clogging."

In regard to purification efficiency, Rudolfs, etal. (2) state that the difference between coarse (2-3 inches) and fine (3/4 to 1 1/2 inches) media is quite marked. "The indications are that with 2 1/2" stone, a filter bed must be several feet deeper than a bed with 1" stone to produce equal intrification."

Shape

The ASCE Manual of Engineering Practice (20) recommends that all the pieces used as trickling filter material should have all three dimensions as nearly equal as possible. Thus the media should have a cubical or spherical shape to give a sufficiently high proportion of voids (16)

The "Ten States Standards" (21) recommend that "The media shall be free from thin elongated pieces and shall not contain more than five percent by weight of pieces with the longest dimensions two times the least dimension."

Schroepfer (14) uses the term shape ratio to express the degree of flatness or elongation of the media. From his studies he concludes that the "shape ratio has very little effect on the surface area and, hence, the efficiency of the trickling filter. However,...there is a tendency for pieces of high shape ratio material to "pile" on one another on the flat sides....This piling may have the effect of increasing the effective size of the media." He also observed that there is an increase in the percentage of voids with an increase in shape ratio.

Durability

The material used as media in trickling filters should not disintegrate into finer material (22). Frequently it is specified that the material be sound or defined by the sodium sulfate soundness test (20).

Payrow (13) in discussing the soundness tests for filter media states that "variations in the technique of applying the sodium sulfate test may cause wide variations in results. The solubility curve for sodium sulfate changes rapidly between temperatures of 0 to 30°C and thus affects the strength of the solution unless constant temperature is obtained." He suggests also that a temperature of 25°C should be used in all the tests.

The British Standards (16) also require that the sodium sulfate test be used as a standard soundness tests, although in preparing the specifications several other tests such as the crushing test and the abrasion test were investigated.

The specifications for media used at Fort Worth, Texas, (17) specified other tests besides the sodium sulfate test, such as the Los Angeles abrasion test, the apparent specific gravity, the absorption test and also indicated that the stones should not contain any organic matter, as shown in Table III.

Table III

Fort Worth Specifications for Filter Stone (17)

Wear, Los Angeles Test (ASTM C131-47)	Not less than 30
Sodium Sulfate Test, 20 cycle, ASCE, Manual 13	Loss not over 10%
Apparent Specific Gravity	Not less than 2.60
Absorption, (ASTM, C 127-42)	Not more than 1%
Organic Matter	none

Placement of Media

Specifications for placing filter media, frequently state that "breakage and segregation of different sized particles should be prevented..." (22). But "no generally acceptable method of placing the media in the filter has been developed which will insure that pockets of fines do not occasionally occur in filters." (17).

Stanley (15) states that many of the trickling filters contain an excessive amount of fine material, most of which was included in the stones as originally placed. Thus if the material is to be transported by truck and placed by dumping directly into the filter bed, there is a tendency to segregate an objectionable amount of the fines in the upper parts of the filter bed.

The specifications for placement of media at Fort Worth, Texas (23) state that "media shall be placed in the filter using a belt conveyor, by boxes, or by other approved methods, which method does not require traffic of any type over the top of the stone placed in the bed..." It was also specified that before placing of the media, it should be passed over a "suitable screen with not less than 1-inch square openings."

Ponding or Clogging of Filters

There are reported to be three general factors that cause trickling filter clogging. The organic and hydraulic loadings of the filter are two important factors and the third is the amount of slime present on the media.

Henkelekian (24) states that the organic loading is more directly related to the biological slime growth than the hydraulic loading. Velz (25) is of a different opinion, since he says that the mass of the zoogloea in the bed is dependent upon the hydraulic ratio of passage of the liquid medium through the bed.

Shepherd (27) attributes the pooling of the bio-filters at Camp Kilmer, N. J., to an excessive growth of Beggiatoa alba, a bacteria which oxidizes sulfides.

It is also believed (28) that most cases of severe ponding of trickling filters are due to over loading. "Over loading may be due to design errors, or it may be due to inadequate capacity for the volume of flow to be treated."

The problem of clogging arises when this biological slime accumulates to such an extent that the void spaces between the filter media become clogged in a certain area (26, 32).

Chase (6) attributes this accumulation of slime to improper filter media. He states that the media should be hard, uniform in size to prevent packing which eventually will cause clogging. Chase also points out that excessively rough material has a tendency to accumulate solids and cause pooling.

Johnson (30) states that the clogging of the trickling filters at the Sanitary District of Elgin, Illinois treatment plant, was occasioned by the desintegration of the filter media due to freezing and thawing.

Jones (31) reports that desintegration does not occur if the original media was durable and free from dust and fines. Tatlock (29) is of the opinion that the ponding is due to poor placing of the media.

Hoodgood (4) and Stanley (10) point out that if fine material enters the filter bed or if it is a product of deterioration of the filter media, it will fill the void spaces, thus reducing the ventilation and at the same time it will prevent the sloughing off of the excess slime growth.

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INTRODUCTION

It has been shown in the review of literature that the ponding or clogging of trickling filters has been attributed to different causes. Most of the research work done on trickling filters has been directed toward the amount of biological slime growth and not much attention has been given to the filter media.

Since the days of the Laurance filter, thousands of trickling filters have been constructed following specifications that seem to be adequate, but many of the filters pond or clog soon after being placed in operation. When a clogged filter is dismantled, it is evident that some small material has accumulated in the void spaces, thus reducing the open spaces. Subsequent biological slime accumulation on the material with small void spaces may produce a ponding condition.

Besides the question of whether the media placement specifications are adequate or not, several other questions in regard to the filter media need to be answered. Some specifications for the placement of trickling filter media imply that the stone fracture in placing them or that there is so much attrition of the stone in the placing operations that a great amount of fines are produced, thus leading to the clogging of the filter.

There is also a question in the mind of some people, as to whether or not some stones produce more fines than other even though they are considered good material if they pass the Sodium Sulfate Soundness Test.

In order to answer some of the questions mentioned and observe the behavior of trickling filter stone, during and after placement, this research was undertaken.

DESCRIPTION OF APPARATUS

Introduction

At the beginning of this study consideration was given to the different testing procedures which would show the ability to fracture or the amount of abrasion that will take place when trickling filter media is placed.

Thus, three standard tests for rocks were considered. The Toughness test, which measures the resistance to fracture under impact; this test requires cylindrical samples of the rock from the quarries, and these could not be obtained.

The second test considered was the Abrasion test of rock by the use of the Deval Machine. It is a general belief that this test does not yield very good results, since the product of the abrasion that takes place on the sample will act as a cushion after a certain time, preventing any further abrasion of the rock sample.

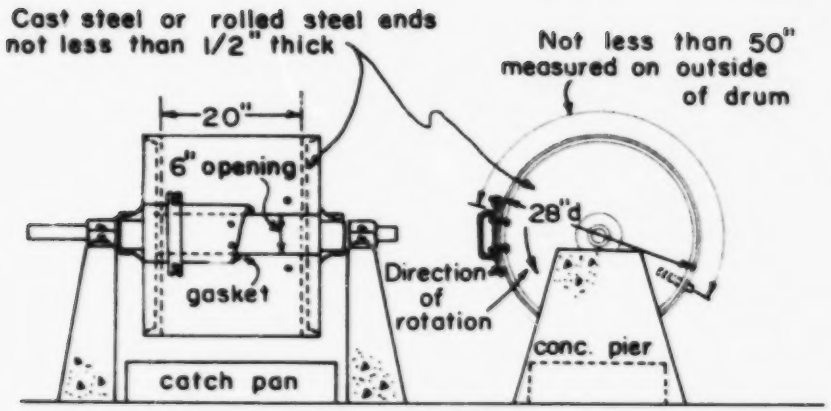
The third test considered was the Abrasion test of rock by the use of the Los Angeles machine, which because of the construction of the machine and the procedure in testing the sample is generally believed to yield better results than with the Deval test. Because of these considerations, the Los Angeles Abrasion test was selected to be used in this study.

Los Angeles Machine

The Los Angeles testing machine is an apparatus designed to test coarse material, like crushed rock, crushed slag, etc., for resistance to abrasion with an abrasive charge.

The Los Angeles machine used was located in the Highway Research Laboratory at Purdue University. This machine conforms in all its essential characteristics to the design shown in Figure 1. The machine consists of a hollow steel cylinder, closed at both ends, having an inside diameter of 28 inches and an inside length of 20 inches. The cylinder is mounted on stub shafts attached to the ends of the cylinder but not entering it, and is mounted in such a manner that it may be rotated about the longitudinal axis in a horizontal position. An opening in the cylinder is provided for the introduction of the test sample. This opening is closed dust-tight with a removable cover bolted in place. The cover is so designed as to maintain the cylindrical contour of the interior surface unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test. A removable wear-resistant steel shelf projecting radially 3.5 inches into the cylinder and extending its full length, is mounted along one element of the interior surface of the cylinder. The shelf is of such a thickness and is so mounted, by bolts, as to be firm and rigid. The position of the shelf is such that the distance from the shelf to the opening, measured along the circumference of the cylinder in the direction of rotation is 50 inches.

Although not used throughout the entire study, as explained in the next chapter, the abrasive charge consisting of steel spheres approximately 1 7/8 inches in diameter and each weighing between 390 and 445 grams were a part of the standard Los Angeles testing machine equipment.



Los Angeles Abrasion Testing Machine

Fig. 1

Sieves

In order to classify the material according to size before and after the Los Angeles Abrasive test, sieves of several dimensions were used.

The larger material (4 to 1½ inches passing) was separated according to sizes by passing it through square openings in a thin piece of plywood. These square openings had the following side dimensions: 4, 3½, 3, 2½, 2 and 1½ inches respectively.

The small material (< 1½ inches passing) was separated by using standard round sieves with square openings. The following sieves of the standard coarse sieves were used: 1, 3/4, 1/2 inches, and the Nos. 4, 6 and 12 sieves of the standard five sieves were used which have the following openings: 0.187, 0.132 and 0.0661 inches respectively.

By this combination of sieves the different fractions of material after the abrasion tests could be determined. The various fractions divisions are shown in Table IV.

Table IV

Fraction Size Range for the Material Retained on the Different Sieves Used in this Study

Material retained on (sieve size)	Fraction size range (inches)
4 in.	4
3 1/2 in.	4.0 - 3.5
3 in.	3.5 - 3.0
2 1/2 in.	3.0 - 2.5
2 in.	2.5 - 2.0
1 1/2 in.	2.0 - 1.5
1 in.	1.5 - 1.0
3/4 in.	1.0 - .75
1/2 in.	.75 - .50
# 4	.50 - .187
# 6	.187 - .132
#12	.132 - .0661
Pan	.0661

PART I

BEHAVIOR OF TRICKLING FILTER STONES UNDER AN ABRASIVE ACTION

Introduction

As stated before, the object of this study was to obtain information on the behavior of trickling filter stone during and after placement in the filter bed. In order to accomplish this purpose, the Los Angeles testing machine was used to subject the stone specimens to an abrasive action.

The first part of this study deals with the adaptability of the Los Angeles Abrasive test to the purpose of this study, by varying the standard procedure used in testing highway construction materials. The data obtained yielded information on the effect of the abrasive action on the stone. The second part deals with the effect of the abraded material on the void spaces between stones.

Experimental Procedure

Stone Samples

During the studies to adapt the standard Los Angeles Abrasive test to the purpose of the study, different samples of stone were used (Table V). These samples were obtained from the Chas. Pfizer and Co., disposal plant, Terre Haute; from the Eli Lilly Co. waste disposal plant, Lafayette; and from the Municipal Sewage Treatment Plants in the following cities: Lebanon, Frankfort, Bloomington, Rochester, Hagerstown, Shelbyville, Kokomo, Osgood and Franklin, all located in the state of Indiana.

The used stone from the Pfizer Chemical Corp. Waste Treatment

TABLE V

Stone Samples Used in this Study

Sample No.	Source
1	Chas. Pfizer Waste Disposal plant, Terre Haute, Ind. (New Stone)
2	Chas. Pfizer Waste Disposal plant, Terre Haute, Ind. (Used Stone)
3	Lebanon Sewage treatment plant, Ind. (Used Stone)
4	Frankfort Sewage treatment plant, Ind. (Used Stone)
5	Bloomington Sewage treatment plant, Ind. (Used Stone)
6	Rochester Sewage treatment plant, Ind. (Used Stone)
7	Hagerstown Sewage treatment plant, Ind. (Used Stone)
8	Shelbyville Sewage treatment plant, Ind. (Used Stone)
9	Kokomo Sewage treatment plant, Ind. (Used Stone)
10	Osgood Sewage treatment plant, Ind. (Used Stone)
11	Franklin Sewage treatment plant, Ind. (Used Stone)
12	Ely Lilly Waste Disposal plant, Lafayette Ind. (New Stone)

Plant was used in a high rate recirculating trickling filter for treatment of wastes from the manufacture of antibiotics. The size of the stones in these filters ranged from stone retained on the 2-inch sieve to stone retained on the 1-inch sieve. This trickling filter presented clogging problems before the stone was replaced with new stone that had a range of sizes from: retained on the 3-inch sieve to stone retained on the 1-inch sieve.

The stone sample from the Lebanon Sewage Treatment Plant was obtained from a standard rate rotatory distributor trickling filter which contained material that ranged from stones retained on the 1-inch sieve.

The stone from the Frankfort Sewage Treatment Plant was obtained from a standard rate fixed nozzle filter, which contained stone in the range of retained on the 2½-inch sieve and retained on the 1-inch sieve.

The stone from the Bloomington Sewage Treatment Plant was obtained from a high rate trickling filter; the stones in the sample were retained on the 1½-inch sieve and on the 1-inch sieve, and showed evidence of age and the edges were rounded.

The stone from the Rochester Sewage Treatment Plant was obtained from a high rate trickling filter; the stones in the sample passed the 3-inch sieve and were retained on the 2-inch sieve. This trickling filter presented clogging problems several times.

The sample of stone from the Hagerstown Sewage Treatment Plant was obtained from a standard rate rotatory distributor trickling filter; the stone in the sample was retained on the 2½-inch sieve and on the 2-inch sieve.

The sample of stone retained on the 2½-inch sieve from the Shelbyville Sewage Treatment Plant was obtained from a standard rate trickling filter.

The sample of stone retained on the 2½-inch sieve from the Kokomo Sewage Treatment Plant was obtained from a high rate trickling filter.

The sample of stone from the Osgood Sewage Treatment Plant had been used in a standard rate rotatory distributor trickling filter; the stones in the sample were retained on the 1½-inch and 1-inch sieves.

The sample of stone from the Franklin Sewage Treatment Plant had been used in a standard and high rate filter; the stone in the sample was retained on the 2½ and 2-inch sieves

The stone sample from the Eli Lilly Waste Disposal Plant was a left over of stone that is being used without clogging problems in a high rate trickling filter for the treatment of pharmaceutical wastes. The stones in the samples ranged from retained on the 3-inch sieve to retained on the 1½-inch sieve.

The samples were washed to remove foreign material. After being cleaned, the stones were dried in an oven at 105° to 110°C (221° to 230°F) to constant weight. For each individual test, the sample consisted of 5,000 ± 25 grams of stone of a certain size.

Method of Testing

During the experimental phase of this study, some stone was subjected to the standard Los Angeles abrasive test with an abrasive change at 500 revolutions. Some stone samples were subjected to a

modified Los Angeles test without abrasive charge at 500 revolutions, and another stone sample was subjected to the modified test at different numbers of revolutions.

In the standard Los Angeles test, the test sample and an abrasive charge of 12 steel spheres were placed in the Los Angeles abrasion machine and the drum of the machine rotated at a speed of from 30 to 33 revolutions per minute. The machine was rotated at this speed for 500 revolutions. At the completion of the test, the material was discharged from the machine and the material smaller than the No. 12 sieve was separated and it constituted the "pan" size material.

The material coarser than the No. 12 sieve, was subjected in some cases to a complete sieve analyses using the following coarse sieves: 3½, 3, 2½, 2, 1½, 1, 3/4, ½ inches and a series of fine sieves: Nos. 4, 6 and 12. After some of the abrasive tests, the material was separated only into 3 fractions: a) material still retained on the initial sieve size; b) material smaller than the No. 12 sieve, and c) the fraction of material between a) and b).

The fractions of material obtained from the sieve analyses were washed, dried in an oven at 105° to 110°C (221° to 230°F) to constant weight, and then weighed to the nearest gram.

Presentation of Data

Test Results Using the Standard Los Angeles Test with Complete Sieve Analyses

The new stone sample from the Pfizer Waste Treatment plant was divided into five sizes as follow: material retained on the 3, 2½, 2, 1½ and 1 inch sieves. Similarly the used stone sample from the Pfizer

Waste Treatment plant was divided into the following sizes: material retained on the 2, 1½ and 1 inch sieves. The used samples from the Lebanon and Frankfort Sewage Treatment Plants were divided into material retained on the 2½, 2, 1½ and 1 inch sieves.

The different sizes of stones from the four different samples were subjected to the Los Angeles Abrasive test with an abrasive charge and 500 revolutions. The material after each test was subjected to a sieve analyses, the results of which are shown in Tables VI through IX.

Test Results Using the Standard Los Angeles Abrasive Test with Partial Sieve Analyses

In order to further compare the characteristics of the different stone samples, a series of standard Los Angeles Abrasive tests were made on stone samples from the Bloomington, Rochester, Hagerstown, Shelbyville, Kokomo, Osgood and Franklin Sewage Treatment Plants. The material after each individual test was discharged from the machine and was screened into three fractions: (a) the material still retained on the initial retaining screen size; (b) the fraction smaller than the No. 12 sieve (pan material), and (c) the intermediate fraction between (a) and (b). The material from fractions (a) and (b) were dried and weighed to the nearest gram. The weights of these two fractions and the percentages of the initial weight are tabulated in Table X for the different samples tested.

Table VI

Sieve Analyses of the Material from Pfiser (New Stone) after the Abrasive Test

Stone Fraction Passing (in.)	Retained (in.)	Initially retained on 3" sieve wt.(gr)	%	Initially retained on 2½" sieve wt.(gr)	%	Initially retained on 2" sieve wt.(gr)	%	Initially retained on 1½" sieve wt.(gr)	%	Initially retained on 1" sieve wt.(gr)	%
3 1/2	3	2206	44								
3	2 1/2	702	14	1696	34						
2 1/2	2	906	18	659	13	1983	38				
2	1 1/2	57	1	883	18	1176	23	2792	54		
1 1/2	1	77	2	153	3	440	9	1120	22	2857	63
1	3/4	17	0	67	1	72	1	45	0	458	10
3/4	1/2	28	1	30	1	28	1	48	1	89	2
1/2	# 4	28	1	8	0	82	2	81	2	82	2
# 4	# 6	8	0	27	1	21	0	24	0	68	1
# 6	#12	22	1	86	2	67	1	67	1	98	2
#12	Pan	909	18	1362	27	1293	25	1021	20	913	20
Totals		4960	100	4971	100	5162	100	5209	100	4565	100

Number of revolutions of Los Angeles testing machine drum: 500

Abrasive charge: 12 steel spheres--size: 1 7/8"; weight: 390-445 grams each

Table VII

Sieve Analyses of the Material from Pfizer (Used Stone) after the Abrasive Test

Stone Fraction		Initially retained on 2" sieve		Initially retained on 1½" sieve		Initially retained on 1" sieve	
Passing (in.)	Retained (in.)	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%
3 1/2	3						
3	2 1/2						
2 1/2	2	2145	43				
2	1 1/2	1687	33	2911	58		
1 1/2	1	177	4	856	17	3118	66
1	3/4	0	0	42	1	491	10
3/4	1/2	47	1	50	1	97	2
1/2	# 4	75	2	75	2	74	1
# 4	# 6	32	1	25	0	60	1
# 6	#12	32	1	62	2	94	2
#12	Pan	736	15	963	19	882	18
Totals		4931	100	4983	100	4816	100

Number of revolutions of Los Angeles testing machine drum: 500

Abrasive charge: 12 steel spheres--Size: 1 7/8"; Weight: 390-445 grams each

Table VIII

Sieve Analyses of the Material from Lebanon (Used Stone) after the Abrasive Test

Stone Fractions		Initially retained on 2½" sieve		Initially retained on 2" sieve		Initially retained on 1½" sieve		Initially retained on 1" sieve	
Passing (in.)	Retained (in.)	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%
3 1/2	3								
3	2 1/2	1832	37						
2 1/2	2	1316	27	2253	46				
2	1 1/2	191	4	1241	25	2757	54		
1 1/2	1	58	1	135	3	1104	22	3057	65
1	3/4	65	1	82	1	35	1	516	11
3/4	1/2	93	2	75	2	42	1	66	1
1/2	# 4	48	1	35	0	68	1	78	2
# 4	# 6	24	0	51	1	27	0	74	1
# 6	#12	82	2	92	2	58	1	93	2
#12	Pan	1252	25	956	19	1030	20	835	18
Totals		4961	100	4920	100	5121	100	4719	100

Number of revolutions of the Los Angeles testing machine drum: 500

Abrasive charge: 12 steel spheres--size: 1 7/8"; weight: 390-445 grams each

Table IX

Sieve Analyses of the Material from Frankfort (Used Stone) after the Abrasive Test

Stone Fractions		Initially retained on 2½" sieve		Initially retained on 2" sieve		Initially retained on 1½" sieve		Initially retained on 1" sieve	
Passing (in.)	Retained (in.)	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%
3 1/2	3								
3	2 1/2	1934	40						
2 1/2	2	1151	24	2337	46				
2	1 1/2	205	4	1282	25	2456	50		
1 1/2	1	75	2	31	0	975	20	2983	63
1	3/4	73	1	42	1	45	1	497	10
3/4	1/2	88	2	24	0	31	0	93	2
1/2	# 4	65	1	78	2	63	1	59	1
# 4	# 6	82	2	65	1	58	1	61	1
# 6	#12	91	2	87	2	76	2	78	2
#12	Pan	1093	22	1152	23	1207	25	1017	21
Totals		4857	100	5098	100	4911	100	4788	100

Number of revolutions of the Los Angeles testing machine drum: 500

Abrasive charge: 12 steel spheres—size: 1 7/8"; weight: 390-445 grams each

Table I

Fractions of stone still retained on initial sive size and material passing the #12 sieve after the Los Angeles test with abrasive charge at 500 revolutions

Bloomington (Used Stone)

Stone Fraction		Initially retained on 1½" sieve		Initially retained on 1¼" sieve		Initially retained on 1" sieve	
Passing	Retained	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%
2	1 1/2	1660	33	1844	36		
1 1/2	1					1579	31
#12	Pan	982	19	1182	23	1252	25
Initial weight		5110	100	5166	100	5117	100

Rochester (Used Stone)

Stone Fraction		Initially retained on 2½" sieve		Initially retained on 2" sieve	
Passing	Retained	wt.(gr)	%	wt.(gr)	%
3	2 1/2	2817	56		
2 1/2	2			1393	27
#12	Pan	726	14	1287	25
Initial weight		5085	100	5121	100

Hagerstown (Used Stone)

Stone Fraction		Initially retained on 2½" sieve		Initially retained on 2" sieve	
Passing	Retained	wt.(gr)	%	wt.(gr)	%
3	2 1/2	1620	31		
2 1/2	2			339	7
#12	Pan	1506	29	931	18
Initial weight		5262	100	5236	100

Table X (cont.)

Shelbyville (Used Stone)

Stone Fraction		Initially retained on 2½" sieve	
Passing	Retained	wt.(gr)	%
3	2 1/2	2089	40
#12	Pan	1002	19
Initial weight		5171	100

Kokomo (Used Stone)

Stone Fraction		Initially retained on 2½" sieve	
Passing	Retained	wt.(gr)	%
3	2 1/2	1584	32
#12	Pan	704	14
Initial weight		4968	100

Osgood (Used Stone)

Stone Fraction		Initially retained on 1½" sieve		Initially retained on 1" sieve	
Passing	Retained	wt.(gr)	%	wt.(gr)	%
2	1 1/2	2251	45		
1 1/2	1			1807	37
#12	Pan	1055	21	1046	21
Initial weight		5000	100	4950	100

Franklin (Used Stone)

Stone Fraction		Initially retained on 2½" sieve		Initially retained on 2" sieve	
Passing	Retained	wt.(gr)	%	wt.(gr)	%
3	2 1/2	1258	25		
2 1/2	2			1831	35
#12	Pan	713	14	824	16
Initial weight		4992	100	5215	100

Test Results Using the Modified Los Angeles Test with Complete Sieve Analyses

Since the abrasion that the stones suffered when subjected to the standard Los Angeles test with an abrasive charge, seemed to be excessive, an attempt to reduce the amount of abrasion was made by subjecting the stone samples to the Los Angeles test without the abrasive charge to more nearly simulate the handling of filter stone in placing them in a filter.

New stone from the Eli Lilly Waste Treatment Plant of different sizes, ranging from retained on the 3-inch sieve to retained on the 1½-inch sieve, was subjected to the modified Los Angeles test. Complete sieve analyses were made on the material after the tests which are shown in Tables XI through XIV.

Test Results Using the Modified Los Angeles Test with Complete Sieve Analyses at Different Lengths of Time

Since during the standard Los Angeles test the stones fall 500 times a distance of 28 inches, it was deemed necessary to observe the behavior of the stones when tested at different lengths of time, thus falling a different number of times a distance of 28 inches without abrasive charge.

New stone from the Eli Lilly Waste Treatment plant, that passed the 3-inch sieve and was retained on the 2½-inch sieve, was tested in the Los Angeles Machine at 100, 200, 300, 400 and 500 revolutions without the abrasive charge. The material after the test was subjected to a complete sieve analyses, the results of which are shown in Table XV.

Table XI

Sieve Analyses of Material from the Eli Lilly Waste Treatment Plant after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction		Sample A		Sample B	
Passing	Retained	wt.	%	wt.	%
3 1/2	3	2437	48	2260	46
3	2 1/2	945	19	641	13
2 1/2	2	437	9	893	18
2	1 1/2	291	6	283	6
1 1/2	1	248	5	182	4
1	3/4	38	1	52	1
3/4	1/2	7	0	65	1
1/2	# 4	15	0	12	0
# 4	# 6	0	0	41	1
# 6	#12	21	0	471	10
#12	Pan	624	12	471	10
Totals		5063	100	4927	100

Initial size of stone: Passing 3½"--Retained 3" sieve

Table XII

Sieve Analysis of Material from New Stone from Eli Lilly Waste Treatment Plant after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Stone Fraction		Sample A		Sample B		Sample C	
Passing	Retained	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%
3	2 1/2	2253	44	2455	48	2384	48
2 1/2	2	2000	39	1510	29	1731	35
2	1 1/2	261	5	596	12	297	6
1 1/2	1	0	0	0	0	0	0
1	3/4	0	0	31	1	0	0
3/4	1/2	0	0	26	0	0	0
1/2	# 4	7	0	10	0	8	0
# 4	# 6	2	0	0	0	12	0
# 6	#12	5	0	12	0	8	0
#12	Pan	596	12	490	10	523	11
Totals		5124	100	5130	100	4963	100

Initial size of stone: Passing 3"--Retained 2½" sieve

Table XIII

Sieve Analyses of Material from the Eli Lilly Waste Treatment Plant after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction		Sample A		Sample B	
Passing	Retained	wt.	%	wt.	%
2 1/2	2	2390	49	2546	50
2	1 1/2	1097	22	1289	25
1 1/2	1	782	16	711	14
1	3/4	19	0	10	0
3/4	1/2	45	1	0	0
1/2	# 4	21	1	3	0
# 4	# 6	20	0	6	0
# 6	#12	18	0	4	0
#12	Pan	520	11	539	11
Totals		4912	100	5108	100

Initial size of stone: Passing 2½"—Retained 2" sieve

Table XIV

Sieve Analyses of Material from the Eli Lilly Waste Treatment Plant after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction		Sample A		Sample B	
Passing	Retained	wt.	%	wt.	%
2	1 1/2	2612	51	2521	50
1 1/2	1	1995	39	1920	38
1	3/4	13	0	49	1
3/4	1/2	18	0	8	0
1/2	# 4	9	0	27	1
# 4	# 6	13	0	16	0
# 6	#12	20	0	18	0
#12	Pan	531	10	514	10
Totals		5211	100	5073	100

Initial size of stone: Passing 2"—Retained on 1½" sieve

Table XV

Sieve Analysis of Material from the Eli Lilly Waste Treatment Plant after the Abrasive Test without Abrasive Charge and at Different Lengths of Time

Passing	Retained	100 Revolutions		200 Revolutions		300 Revolutions		400 Revolutions		500 Revolutions	
		wt.(gr)	%	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%	wt.(gr)	%
3	2 1/2	4682	97	4155	85	3000	62	2911	57	2823	56
2 1/2	2	0	0	396	8	834	18	956	19	831	16
2	1 1/2	0	0	0	0	210	4	523	10	575	11
1 1/2	1	0	0	0	0	193	4	121	2	113	2
1	3/4	0	0	0	0	33	0	0	0	98	2
3/4	1/2	0	0	0	0	26	0	0	0	0	0
1/2	# 4	0	0	9	0	86	2	26	1	7	0
# 4	# 6	4	0	22	0	56	1	39	1	39	1
# 6	#12	16	1	16	0	63	1	50	1	84	2
#12	Pan	112	2	323	7	367	8	450	9	494	10
Totals		4814	100	4921	100	4873	100	5076	100	5064	100

Initial size of samples: Passing 3"—Retained 2½"

Effect of the Abrasive Charge on the Results of the Los Angeles Abrasive Test at 500 Revolutions

In order to have a basis of comparison between the results of the Los Angeles tests with and without the abrasive charge, a sample of the stone from the Eli Lilly Waste Treatment Plant, that passed the 3-inch sieve and was retained on the 2½-inch sieve, was subjected to the abrasive test with the abrasive charge. It was not deemed necessary for the comparison purposes to subject the material after the test to a complete sieve analyses, thus only a partial sieve analyses was made obtaining the results shown in Table XVI.

Table XVI

Results of the Sieve Analyses of a Stone Sample from the Eli Lilly Waste Treatment Plant after the Los Angeles Test with an Abrasive Charge at 500 Revolutions

Stone Fraction		Initially retained on 2½" sieve	
Passing	Retained	weight (gr)	%
3	2 1/2	2840	57
#12	Pan	1245	25
Initial weight		4981	100

Consistency of the Results of the Los Angeles Test with Abrasive Charge

In order to observe the consistency of the results of the Los Angeles test with an abrasive charge at 500 revolutions, two duplicate tests were performed, one on stone initially retained on the 2½-inch sieve from the new stone sample from the Pfizer Waste Treatment Plant and another on 1½-inch stone from the Bloomington Sewage Treatment Plant. The results of the sieve analyses for these duplicate samples after the abrasive test, are shown in Table XVII with the results of the sieve analyses for the initial run on the samples.

Discussion of Results

Comparison of the Results of the Los Angeles Test with Abrasive Charge at 500 Revolutions

In order to evaluate the different samples of stone and since not all the samples have the same sizes of stone, it was necessary to convert the results to a common denominator. The stone samples from the Pfizer Waste Treatment Plant (new stone), from the Lebanon and Frankfort Sewage Treatment Plants have the same size of stone, therefore the results of sieve analyses after the Los Angeles test with abrasive charge at 500 revolutions, which were presented in Tables II, IV and V, were used as a basis for the conversion to a common denominator of the different sizes tested from the different samples.

The tabulation for the loss in weight and the amount of pan size material for the three samples of stone before mentioned, are shown in Table XVIII. The averages for the different initial sizes ranging from 2½ inches to 1 inch were plotted in Figures 2 and 3. With the

Table XVII

Results of the Sieve Analyses on Duplicate Samples of Stone after the Los Angeles Test with Abrasive Charge at 500 Revolutions

Pfizer Waste Treatment Plant (New Stone)

Stone Fraction		Initial Test Initially retained on 2½" sieve		Duplicate Test Initially retained on 2½" sieve	
Passing (in.)	Retained (in.)	wt.(gr)	%	wt.(gr)	%
3	2 1/2	1696	34	2300	45
2 1/2	2	659	13	1457	28
2	1 1/2	883	18	0	0
1 1/2	1	153	3	19	0
1	3/4	67	1	37	0
3/4	1/2	30	1	52	1
1/2	# 4	8	0	72	2
# 4	# 6	27	1	19	0
# 6	#12	86	2	67	2
#12	Pan	1362	27	1113	22
Totals		4971	100	5136	100

Bloomington Sewage Treatment Plant

Stone Fraction		Initial Test Initially retained on 1½" sieve		Duplicate Test Initially retained on 1½" sieve	
Passing (in.)	Retained (in.)	wt.(gr)	%	wt.(gr)	%
2	1 1/2	1660	33	1844	36
#12	Pan	982	19	1182	23
Initial weight		5110	100	5166	100

Table XVIII

Tabulation of Loss in Weight and Amount of Pan Size Material for Samples with Similar Sizes of Stone

Loss in weight (%)

Source	Initial sizes of stone			
	2½"	2"	1½"	1"
Pfizer (New)	66	62	46	37
Lebanon	63	54	46	35
Frankfort	60	54	50	37
Average	63	57	47	36

Pan size material (%)

Source	Initial sizes of stone			
	2½"	2"	1½"	1"
Pfizer (New)	27	25	20	20
Lebanon	25	19	20	18
Frankfort	22	23	25	21
Average	25	22	22	20

Note: The percentages tabulated were obtained from the sieve analyses of the material after the Los Angeles test with abrasive charge at 500 revolutions.

aid of these Figures, the loss in weight and the amount of pan size material of all the stones tested with abrasive charge, were reduced to a nominal initial size of 2 inches when tested in the Los Angeles machine with an abrasive charge at 500 revolutions. The equivalent values for the loss in weight are tabulated in Table XIX, and the equivalent values for the amount of pan size material are tabulated in Table XX.

The average percentages for the loss in weight for the three samples of stone with common sizes, shows that there is a difference between the different sizes of stone, but there is no appreciable difference in the percentages for each individual size of stone. Also the average percentages for the pan size material for the three samples of stone with common sizes, shows that there is a difference in the amount of pan size material between the different sizes of stone, but again there is no appreciable difference between the percentages for each individual size of stone. This consideration makes it necessary to convert all the results to a common denominator for comparison purposes.

Comparison of the Results of the Los Angeles Test without Abrasive Charge at 500 Revolutions

In order to further evaluate the different samples of stone, the results of the loss in weight and the amount of pan size material from the Los Angeles tests with abrasive charge at 500 revolutions had to be converted to a nominal initial size of 2 inches when tested without the abrasive charge. The results of the same two parameters from the Los Angeles tests without the abrasive charge had also to

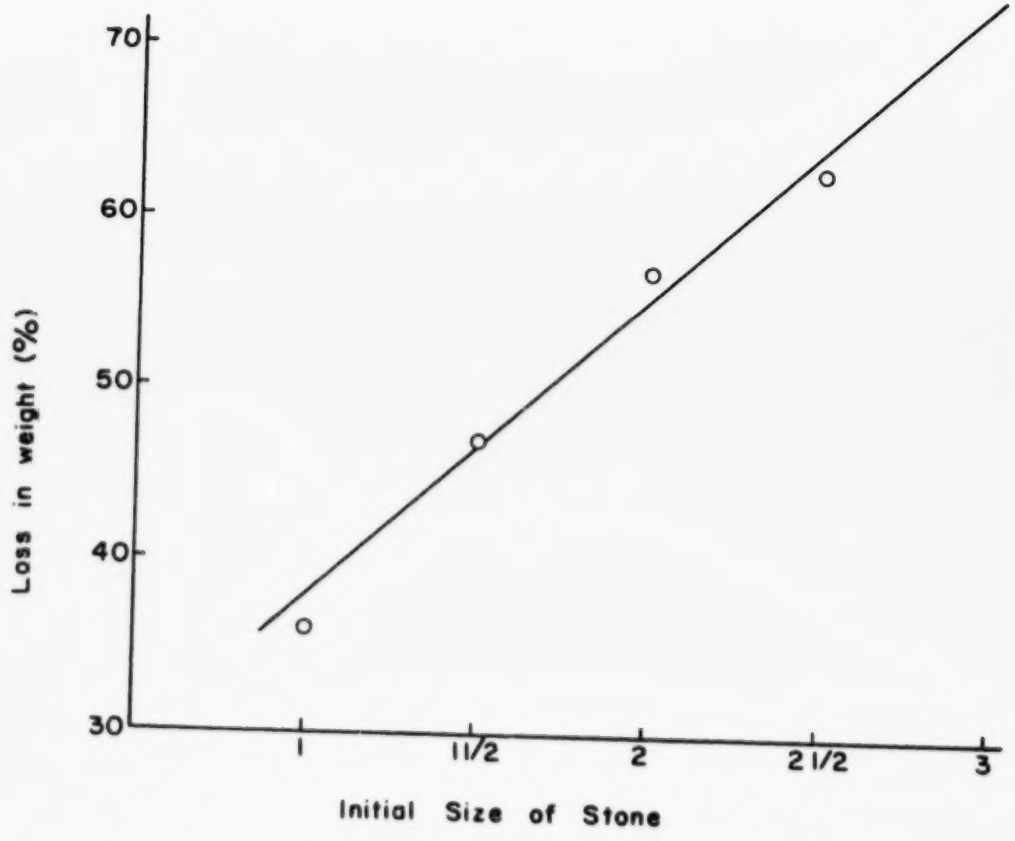


Fig. 2 Relationship Between Stone Sizes and Loss in Weight after the Los Angeles Abrasive Test with Abrasive Charge at 500 revolutions

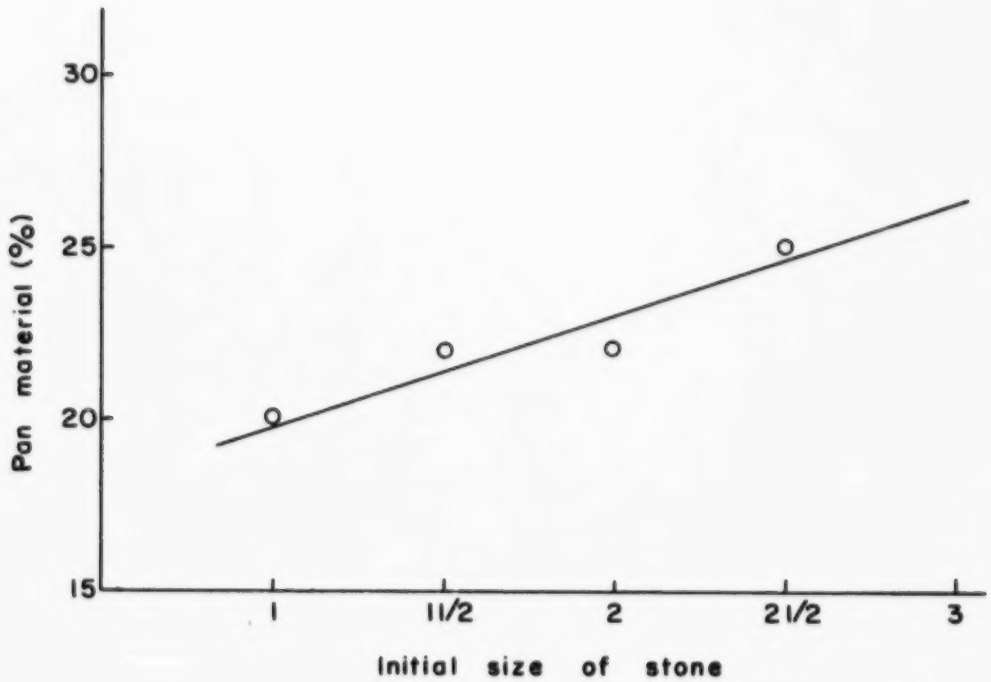


Fig. 3 Relationship between stone sizes and amount of pan size material after the Los Angeles Abrasive test with abrasive charge at 500 rev.

Table XIX

Tabulation of the Loss in Weight after the Los Angeles Test with Abrasive Charge at 500 Revolutions Equivalent to a Nominal Size of 2 Inches

Source and Initial size		Actual Loss in wt.	Equivalent Loss in wt.	Averages
Pfizer (New)	3 "	56	38	
	2½"	66	57	
	2½"	55	46	
	2 "	62	62	
	1½"	46	55	
	1 "	37	55	52
Pfizer (Used)	2 "	57	57	
	1½"	42	51	
	1 "	34	52	53
Lebanon	2½"	63	54	
	2 "	54	54	
	1½"	46	55	
	1 "	35	52	54
Frankfort	2½"	60	51	
	2 "	54	54	
	1½"	50	59	
	1 "	37	55	55
Bloomington	1½"	67	76	
	1½"	64	73	
	1 "	69	87	79
Rochester	2½"	44	35	
	2 "	73	73	54
Hagerstown	2½"	69	60	
	2 "	93	93	77
Shelbyville	2½"	60	51	51
Kokomo	2½"	68	59	59
Osgood	1½"	55	64	
	1 "	63	81	73
Franklin	2½"	75	66	
	2 "	65	65	66

Table XX

Tabulation of the Amount of Pan Size Material after the Los Angeles Test with Abrasive Charge at 500 Revolutions Equivalent to a Nominal Size of 2 Inches

Source and Initial size		Actual amount pan size	Equivalent amount pan size	Averages
Pfizer (New)	3 "	18	15	
	2½"	27	26	
	2½"	22	21	
	2 "	25	25	
	1½"	20	22	
	1 "	20	23	22
Pfizer (Used)	2 "	15	15	
	1½"	19	21	
	1 "	18	21	19
Lebanon	2½"	25	23	
	2 "	19	19	
	1½"	20	22	
	1 "	18	21	21
Frankfort	2½"	22	20	
	2 "	23	23	
	1½"	25	27	
	1 "	21	24	24
Bloomington	1½"	19	21	
	1½"	23	25	
	1 "	25	28	25
Rochester	2½"	14	13	
	2 "	25	25	19
Hagerstown	2½"	29	27	
	2 "	18	18	23
Shelbyville	2½"	19	17	17
Kokomo	2½"	14	12	12
Osgood	1½"	21	23	
	1 "	21	24	24
Franklin	2½"	14	12	
	2 "	16	16	14

be converted to the nominal initial size of 2 inches.

A tabulation of the percentages of loss in weight after the Los Angeles test without the abrasive charge are shown in Table XXI for stone from the Eli Lilly Waste Treatment Plant: retained initially on the 3, 2½, 2 and 1½ inch sieves, yielding a loss in weight of 53, 52, 51 and 50 percent respectively. In the same Table the percentages of pan size material are tabulated for the same stone and the same sizes yielding an amount of pan size material of 11, 11, 11 and 10 percent respectively.

As can be noticed, from the percentages presented in Table XXI, there is some difference between the average results for the different sizes for the loss in weight and the amount of pan size material. Thus it is necessary to convert the percentages of those two parameters to a common denominator for comparison purposes.

The averages for the loss in weight were plotted on Figure 4 and the averages for the amounts of pan size material were plotted on Figure 5. In order to correlate the results of the tests with and without the abrasive charge, the difference for the loss in weight and the amount of pan size material when tested with and without the abrasive charge are tabulated in Table XXII. From this Table it can be observed that there is a arithmetical difference of 8 percent in the percent of weight lost by the sample during the tests, and it also can be observed that there is a 14 percent arithmetical difference in the amounts of pan size material produced during the tests.

Table XXI

Tabulation of the Loss in Weight and the Pan Size Material after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Loss in weight (%)

Source	Stone initially retained on:			
	3"	2½"	2"	1½"
Eli Lilly	52	56	51	49
	54	52	50	50
		52		
		44		
Average	53	52	51	50

Pan size material (%)

Source	Stone initially retained on:			
	3"	2½"	2"	1½"
Eli Lilly	12	12	11	10
	10	10	11	10
		11		
		10		
Average	11	11	11	10

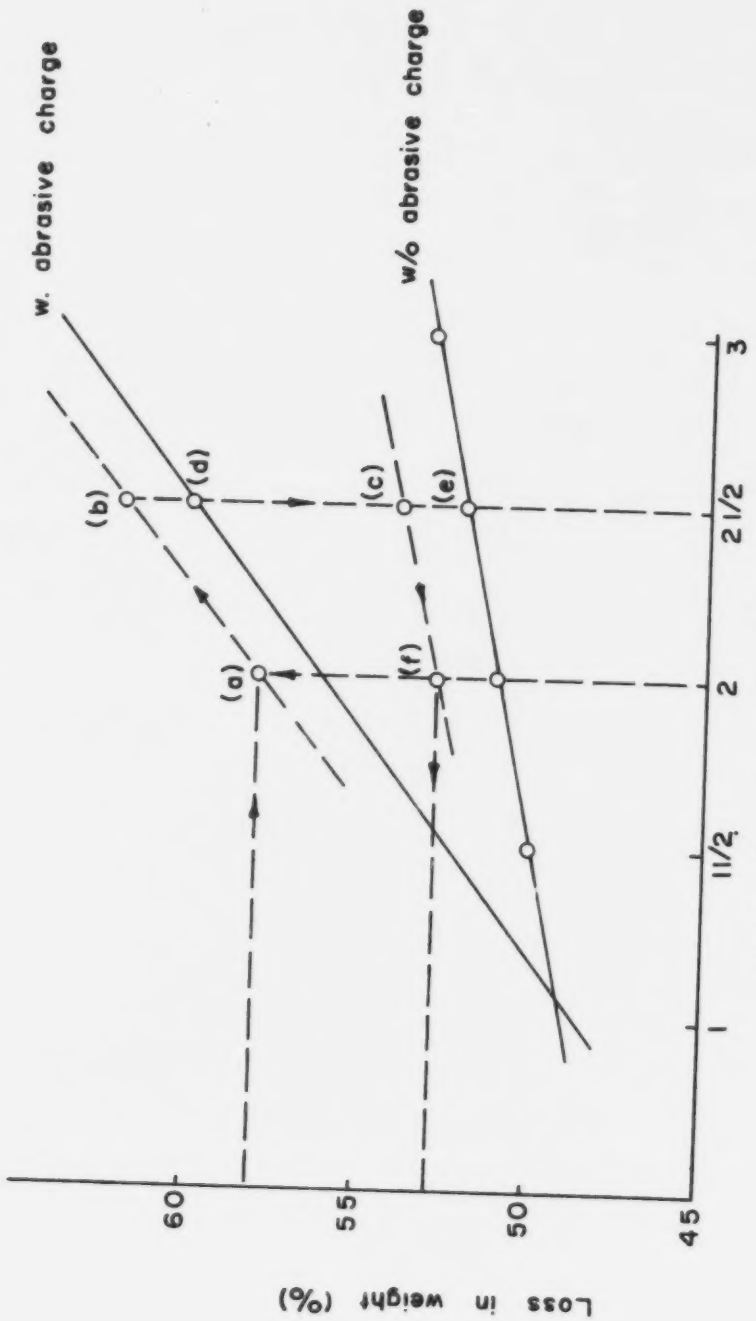


Fig. 4 Relationship between sizes of stone and the loss in weight after the Los Angeles Test without an abrasive charge at 500 revolutions

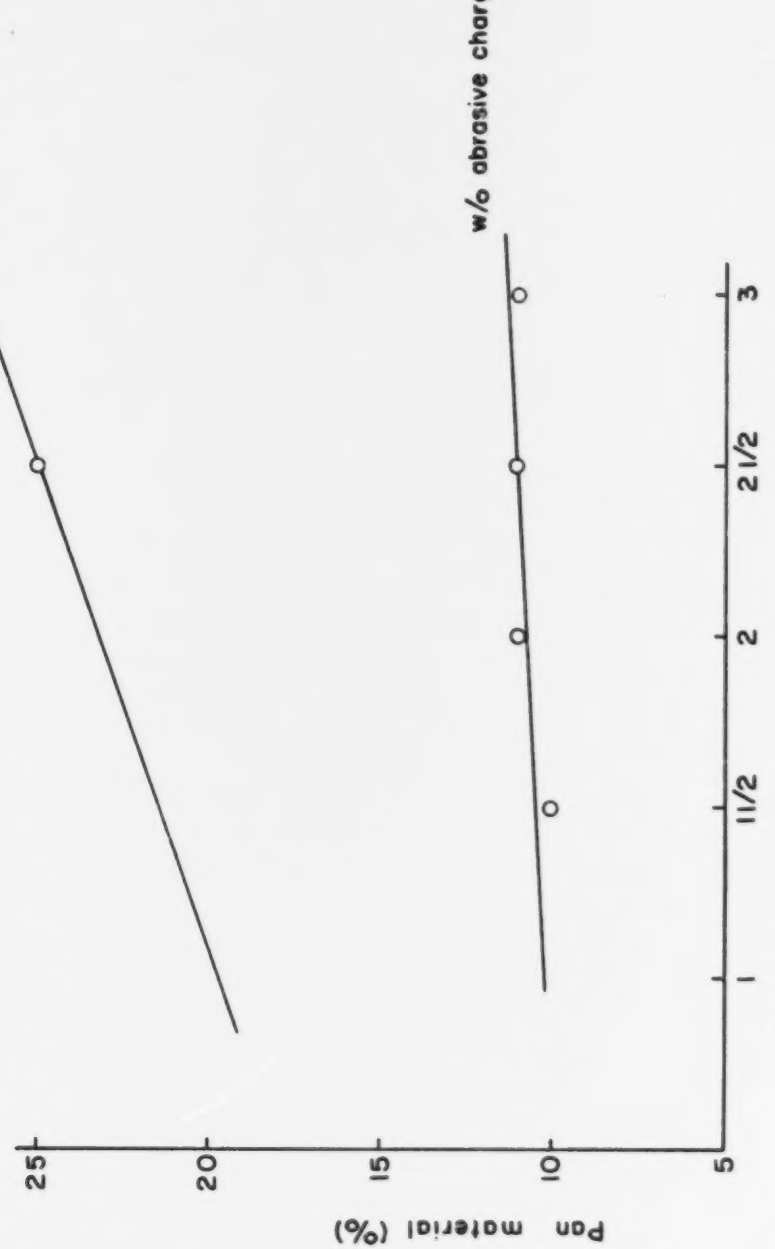


Fig. 5 Relationship between the sizes of stone and the amount of pan size material after the Los Angeles Test without abrasive charge at 500 rev.

Table XXII

Tabulation of the Loss in Weight of the Sample and the Pan Size Material after the Los Angeles Test at 500 Revolutions

Abrasive Charge	Loss in weight %	Pan Size material %	Comments
without abrasive charge	51	11	average for 4 tests
with abrasive charge	43	25	1 test
Difference	8	14	

Note: Stone retained on 2½-inch sieve from the Eli Lilly sample

A point showing the arithmetical difference of 8 percent in the weight lost by the sample during the test was plotted on Figure 4 for the 2½-inch stone. Through this point a line with the same slope as the average line shown on Figure 2 was drawn. On Figure 5, a point showing the arithmetical difference of 14 percent in the amount of pan size material, was plotted. Through this point a line with the same slope as the average line shown on Figure 3 was drawn.

With the aid of Figures 4 and 5, all the percentages for the loss in weight and the amount of pan size material were converted to the nominal initial size of 2 inches when tested without the abrasive charge at 500 revolutions. The equivalent percentages obtained are tabulated in Tables XXIII and XXIV.

Since the two lines on Figures 4 and 5 are not parallel, the convertion of percentages from the Los Angeles test with abrasive charge to without abrasive charge, has to be made as follows: Assume that a sample of 2-inch stone was subjected to the Los Angeles test with an abrasive charge yielding a loss in weight of 58 percent and the ordinate through the 2-inch stone intersect at point (a). Through point (a) a line is drawn parallel to the line representing the variation of the results of the abrasive test with the abrasive charge. This line is followed till it intercepts the ordinate of the 2½-inch stone at point (b), which represents the equivalent loss in weight of a 2½-inch stone when tested with abrasive charge. Following the ordinate of the 2½-inch stone downwards, point (c) is located such that the ratio of the ordinates of (d) and (e) is equal to the

Table XXIII

Tabulation of the Loss in Weight after the Los Angeles Tests
Equivalent to a Nominal Size of 2 Inches
When Tested without Abrasive Charge at 500 Revolutions

Source and initial size		Actual loss in wt.	Equivalent loss in wt.	Averages
Pfizer (New)	3 "	56	43	
	2½"	66	57	
	2½"	55	46	
	2 "	62	57	
	1½"	46	45	
	1 "	37	40	48
Pfizer (Used)	2 "	57	52	
	1½"	42	41	
	1 "	34	37	43
Lebanon	2½"	63	54	
	2 "	54	49	
	1½"	46	45	
	1 "	35	38	47
Frankfort	2½"	60	51	
	2 "	54	49	
	1½"	50	49	
	1 "	37	40	47
Bloomington	1½"	67	66	
	1½"	64	63	
	1 "	69	72	67
Rochester	2½"	44	35	
	2 "	73	68	51
Hagerstown	2½"	69	60	
	2 "	93	88	74
Shelbyville	2½"	60	51	51
Kokomo	2½"	68	59	59
Osgood	1½"	55	54	
	1 "	63	65	64
Franklin	2½"	75	66	
	2 "	65	60	63

Table XXIII (cont.)

Source and initial size		Actual loss in wt.	Equivalent loss in wt.	Averages
Eli Lilly	3 "	52	50	
	3 "	54	52	
	2¼"	56	55	
	2¼"	52	51	
	2¼"	52	51	
	2¼"	44	43	
	2 "	51	51	
	2 "	50	50	
	1¾"	49	50	
	1½"	50	51	50

Table XXIV

Tabulation of the Amount of Pan Size Material after the Los Angeles Tests Equivalent to a Nominal Size of 2 Inches When Tested without Abrasive Charge at 500 Revolutions

Source and initial size		Actual pan size material	Equivalent pan size material	Averages
Pfizer (New)	3 "	18	2	
	2½"	27	13	
	2½"	22	8	
	2 "	25	13	
	1½"	20	9	
	1 "	20	11	8
Pfizer (Used)	2 "	15	3	
	1½"	19	8	
	1 "	18	9	7
Lebanon	2½"	25	11	
	2 "	19	7	
	1½"	20	9	
	1 "	18	9	9
Frankfort	2½"	22	8	
	2 "	23	11	
	1½"	25	14	
	1 "	21	12	11
Bloomington	1½"	19	8	
	1½"	23	12	
	1 "	25	16	12
Rochester	2½"	14	0	
	2 "	25	13	7
Hagerstown	2½"	29	15	
	2 "	18	6	11
Shelbyville	2½"	19	5	5
Kokomo	2½"	14	0	0
Osgood	1½"	21	10	
	1 "	21	12	11
Franklin	2½"	14	0	
	2 "	16	4	2

Table XXIV (cont.)

Source and initial size		Actual pan size material	Equivalent pan size material	Averages
Eli Lilly	3 "	12	12	
	3 "	10	10	
	2½"	12	12	
	2½"	10	10	
	2½"	11	11	
	2½"	10	10	
	2 "	11	11	
	2 "	11	11	
	1½"	10	10	
	1½"	10	10	11

ratio of the ordinates of points (b) and (c). Through point (c) a line is drawn parallel to the line representing the variation of the results of the abrasive test without the abrasive charge. This line is followed till it intercepts the ordinate of the 2-inch stone at point (f). Then the equivalent percentage of 52.60 percent can be read off on the abscissa axis. The same procedure is utilized when Figure 5 is used to obtain the equivalent percentage of pan size material.

Effect of the Number of Revolutions on the Results of the Los Angeles Test without Abrasive Charge

In the foregoing discussion the stones have been evaluated on the basis of nominal initial size of 2 inches after falling 500 times a distance of 28 inches. In order to observe the behavior of the stone when it falls 100 times a distance of 28 inches, the results of the loss in weight and the pan size material had to be established.

The loss in weight of a sample of stone and the amount of pan size material produced, are tabulated for different numbers of revolutions in Table XXV and plotted in Figure 6. A tabulation of the percentage of loss in weight and pan size material with respect to the results at 500 revolutions is also shown in Table XXV. In order to convert the percentages of loss in weight and pan size material to a common denominator all the percentages have to be converted first to a nominal initial size (2 inches) when tested without the abrasive charge at 500 revolutions. Once the percentages are converted to the nominal initial size, the equivalent percentages of loss in weight and pan size material are multiplied by the factors given in Table XXV

Table XXV

Tabulation of the Loss in Weight and the Amount of Pan Size Material, after the Los Angeles Test without Abrasive Charge

No. of Revolutions	Loss in weight %	%	Pan size material %	%
0	0	0	0	0
100	3	6.8	2	20.0
200	15	34.1	7	70.0
300	38	86.5	8	80.0
400	43	98.0	9	90.0
500	44	100.0	10	100.0

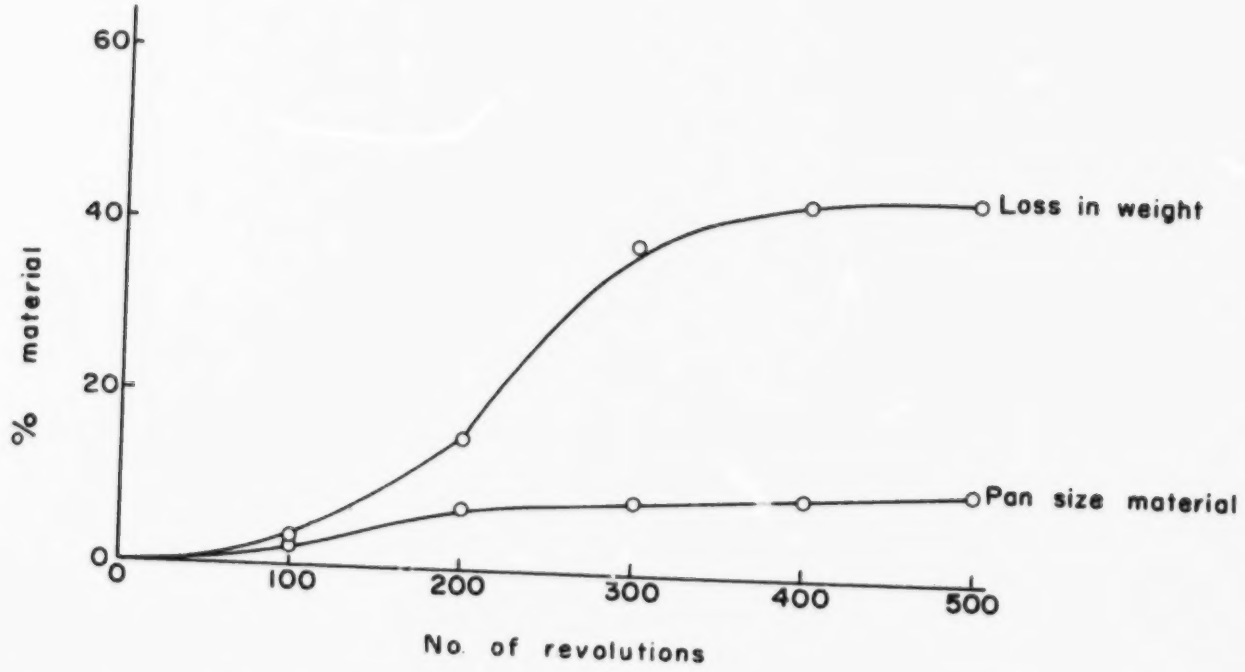


Fig. 6 Relationship between the No. of revolutions and the pan size material and the loss in weight after the Los Angeles Test without abrasive charge.

for the loss in weight and the pan size material respectively to arrive at an equivalent value of the percentages at any desired number of revolutions. The converted percentages for loss in weight and pan size material at 100 revolutions are tabulated in Table XXVI.

A mathematical expression for the curve of loss in weight of Figure 6 has been developed and is presented in Appendix A of this study.

Consistency of the Results of the Los Angeles Test with Abrasive Charge

The results of the sieve analyses on the Pfizer Waste Treatment Plant stone showed that the initial weight of material suffered a loss in weight during the abrasive test of 66 percent for the initial test and 55 percent for the duplicate test, which indicates a difference of 17 percent. The stones from the Bloomington Sewage Treatment Plant showed a loss in weight after the test of 67 percent for the initial test and 64 percent for the duplicate test, which indicates a difference of only 4 percent.

The pan size material for the stone of the Pfizer Waste Treatment Plant yielded 27 percent for the initial test and 22 percent for the duplicate test, for a difference of 19 percent. The stone from the Bloomington Sewage Treatment Plant yielded 19 percent for the initial test and 23 percent for the duplicate test, for a difference of 17 percent.

Table XXVI

Tabulation of the Equivalent Values of the Loss in Weight and the Pan Size Material to a Nominal Initial Sizes of 2 Inches When Tested without Abrasive Charge at 100 Revolutions

Source and Initial size of stone		Actual loss in wt. (%)	Equivalent loss in wt. (%)	Average (%)	Actual pan size material (%)	Equivalent pan size material (%)	Average (%)
Pfizer (New)	3 "	56	3		18	0	
	2½"	66	4		27	3	
	2½"	55	3		22	2	
	2 "	62	4		25	3	
	1½"	46	3		20	2	
	1 "	37	3	3	20	2	2
Pfizer (Used)	2 "	57	4		15	1	
	1½"	42	3		19	2	
	1 "	34	3	3	18	2	2
Lebanon	2½"	63	4		25	2	
	2 "	54	3		19	1	
	1½"	46	3		20	2	
	1 "	35	3	3	18	2	2
Frankfort	2½"	60	3		22	2	
	2 "	54	3		23	2	
	1½"	50	3		25	3	
	1 "	37	3	3	21	2	2
Bloomington	1½"	67	4		19	2	
	1½"	64	4		23	2	
	1 "	69	5	4	25	3	2

Table XXVI (cont.)

Source and Initial size of stone		Actual loss in wt. (%)	Equivalent loss in wt. (%)	Average (%)	Actual pan size material (%)	Equivalent pan size material (%)	Average (%)
Rochester	2½"	44	2		14	0	
	2 "	73	5	3	25	3	2
Hagerstown	2½"	69	4		29	3	
	2 "	93	6	5	18	1	2
Shelbyville	2½"	60	3	3	19	1	1
Kokomo	2½"	68	4	4	14	0	0
Osgood	1½"	55	4		21	2	
	1 "	63	4	4	21	2	2
Franklin	2½"	75	4		14	0	
	2 "	65	4	4	16	1	1
Eli Lilly	3 "	52	3		12	2	
	3 "	54	4		10	2	
	2½"	56	4		12	2	
	2½"	52	3		10	2	
	2½"	52	3		11	2	
	2½"	44	3		10	2	
	2½"	43	3		9	2	
	2½"	38	3		8	2	
	2½"	15	3		7	2	
	2½"	3	3		2	2	
	2 "	51	3		11	2	
	2 "	50	3		11	2	
	1½"	49	3		10	2	
	1½"	50	3	3	10	2	2

Summary

During this part of the study, an effort was made to observe the behavior of the stone when subjected to an abrasive action, and to compare the results obtained from the abrasive tests on the different stone samples.

From the foregoing discussion of data it is apparent that the stone fractures to some extent when subjected to an abrasive action, which can be observed from the summary of the equivalent percentages of loss in weight for a nominal initial size of 2 inches when tested without abrasive charge at 100 revolutions, presented in Table XXVII.

The summary of the equivalent percentages of pan size material for a nominal initial size of 2 inches when tested without abrasive charge at 100 revolutions presented in Table XXVIII, indicates that there is some pan size material produced although the quantity is very small.

A study of Figure 6 indicates that if the stone falls 10 times a distance of 28 inches, the amounts of weight lost and the pan size material will be so small that they can not be measured, being therefore negligible.

Furthermore, from Tables XXVII and XXVIII, it is apparent that the samples from the Pfizer Waste Treatment Plant (used stone) and from the Rochester Sewage Treatment Plant which have had some clogging problems did not show any difference with respect to the other samples of stone, indicating that the character of the stone was probably not a cause for the clogging of those filters.

Table XXVII

Summary of the Average Equivalent Percentages of Loss in Weight of the Nominal Initial Size When Tested without the Abrasive Charge at 100 Revolutions

Source	Percentage
Hagerstown	5
Franklin	4
Osgood	4
Bloomington	4
Kokomo	4
ROCHESTER	3
Shelbyville	3
Eli Lilly	3
Pfizer (New)	3
Lebanon	3
Frankfort	3
PFIZER (Used)	3
Average	4

Table XXVIII

Summary of the Average Equivalent Percentages of Pan Size Material of the Nominal Initial Size When Tested without the Abrasive Charge at 100 Revolutions

Source	Percentage
Bloomington	2
Hagerstown	2
Osgood	2
Eli Lilly	2
Frankfort	2
ROCHESTER	2
Pfizer (New)	2
Lebanon	2
PFIZER (Used)	2
Shelbyville	1
Franklin	1
Kokomo	0
Average	2

PART II

EFFECT OF THE ABRADED MATERIAL ON THE VOID SPACES

Introduction

It is a general belief, as shown in the review of literature, that the void spaces between the stones of trickling filters fill up with fine material, thus producing a ponding situation. In Part I of this study it was shown that the stone when subjected to an abrasive action produces some amount of fine material, thus in this Part the effect that the fine material has on the void spaces between the stones will be studied.

Experimental Procedure

Determination of the Total Volume of Sample

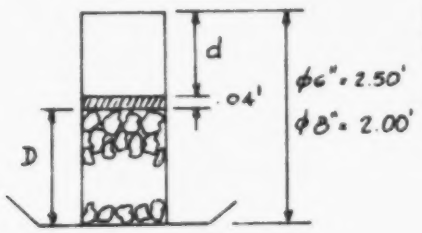
In order to determine the total volume of the sample, 6 and 8-inch galvanized iron cylinders were used as containers in the test. The sample was placed in the cylinders, one at a time, after which the depth of stone was measured and the volume of the sample was calculated by multiplying the cross-sectional area of the cylinder by the depth of the stone in the cylinder. A sample calculation of the total volume of sample is shown in Table XXIX.

Due to the size of the stones to be tested in this study, the 8-inch galvanized iron cylinder was used for further tests.

Table XXIX

Sample Calculations for the Dilumination of Total Volume of a Sample of Stone before Abrasion in the Los Angeles Testing Machine without Abrasive Charge at 500 Revolutions

Run No.	d(ft) (1)	Pipe 8" d-.04' (2)	D(ft) (3)	V(in^3) (4)	d(ft) (1)	Pipe 6" d-.04' (2)	D(ft) (3)	V(in^3) (4)
1	1.32	1.36	.64	38.6	1.60	1.64	.86	29.2
2	1.28	1.32	.68	41.0	1.55	1.59	.91	30.8
3	1.28	1.32	.68	41.0	1.62	1.66	.84	28.5
4	1.25	1.29	.71	42.8	1.50	1.54	.96	32.6
5	1.27	1.31	.69	41.6	1.62	1.66	.84	28.5
6	1.23	1.27	.73	44.0	1.59	1.63	.87	29.5
7	1.29	1.33	.67	40.4	1.57	1.61	.89	30.2
8	1.30	1.34	.66	39.8	1.61	1.65	.85	28.9
9	1.29	1.33	.67	40.4	1.59	1.63	.87	29.5
10	1.33	1.37	.63	38.0	1.58	1.62	.88	29.8
Ave.				40.76				29.75



(1) dimension d
(2) d + .04'
(3) 8" pipe: 2.00' - (d + .04)
6" pipe: 2.50' - (d + .04)
(4) 6" pipe: 339.12 in^3/ft of depth x D
8" pipe: 602.68 in^3/ft of depth x D

Source of sample: Eli Lilly Waste Treatment Plant

Determination of the Volume of Void Spaces

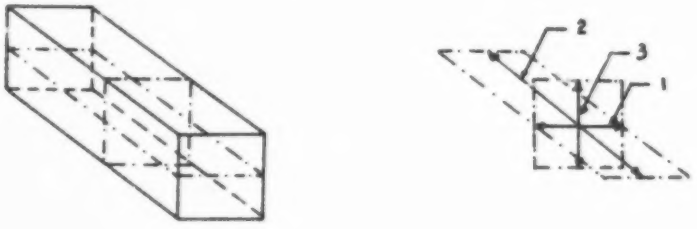
The volume of the void spaces between the stones of a sample was determined as follows:

An 8-inch galvanized iron cylinder two feet in height was filled with the sample of stone and a uniform sand. The unit weight of the sand was previously determined as shown in Table XIX and it was found to be 95 lbs./cu.ft. The stone and the sand were placed in the cylinder by layers so that the sand filled all of the void spaces. The weights of the cylinder without the stone and with the stone were recorded. The weight of the cylinder plus stone plus sand was determined ten times as shown in Table XIX, and the average of the ten weights was used in the computations for the volume of void spaces.

Determination of the Sizes of Stone and Void Spaces

Having determined the total void space volumetrically, the actual size of the stones and the void spaces had to be determined. In order to measure the stones the following procedure was used:

With a caliper, the minimum dimension was measured at right angles to the maximum dimension. These two measurements determined a plane. Then the length of a second plane at right angles to the plane though the maximum dimension was measured.



Planes through, and Dimensions of an Idealized Stone or Void Space

Table XXI

Sample Calculations for the Total Volume of Void Spaces in a Sample of Stone

Unit Weight of Sand

wt. of bucket = 1.156 kg
wt. of bucket + sand = 10.156 kg
wt. of sand = 9.000 kg
= 19.83 lbs.

volume of sand = .2089 cu. ft.

$$\text{unit wt.} = \frac{19.83}{.2089} = 95 \text{ lbs/cu.ft.}$$

Total Volume of Voids

Sample A

wt. pan + 8" pipe =	2,728 gr
wt. pan + pipe + stone =	6,893 gr
wt. pan + pipe + stone + sand =	7,113 gr
	7,121 gr
	7,109 gr
	7,107 gr
	7,117 gr
	7,119 gr
	7,114 gr
	7,123 gr
	7,109 gr
	7,115 gr
average =	7,115 gr

$$\begin{array}{r} 7,115 \\ -\ 6,893 \\ \hline \end{array}$$

wt. of sand = 222 gr = .490 lbs.

$$\text{volume of voids in sample} = \frac{.490 \text{ lbs}}{95 \text{ lbs/cu.ft.}} = .00516 \text{ cu.ft.}$$

Table XXX (cont.)

Sample B

wt. of pan + 8" pipe =	2,728 gr
wt. of pan + pipe + stone =	7,852 gr
.wt. of pan + pipe + stone + sand =	8,115 gr
	8,109 gr
	8,112 gr
	8,121 gr
	8,105 gr
	8,110 gr
	7,996 gr
	8,117 gr
	8,112 gr
	8,102 gr
average =	8,100 gr

$$\text{wt. of sand} = \begin{array}{r} 8,100 \\ -\ 7,852 \\ \hline 248 \text{ gr} \end{array} = .546 \text{ lbs}$$

$$\text{Total volume of voids in sample} = \frac{.546}{95} = .00576 \text{ cu.ft.}$$

The three dimensions measured were numbered as follows: (1) represents the smallest dimension; (2) represents the largest dimension perpendicular to the smallest dimension; and, (3) represents the dimension perpendicular to the plane defined by (1) and (2).

In order to measure the dimensions of the void spaces, the void space had to be cast with paraffin wax and the three axis measured the same as for the stone. The casting of a void space was done by arranging at random some stones on a flat surface so that they enclosed a void space. Then plasticine was used to seal the joints of the stones so that the melted paraffin could not flow out of the space to be cast. After the paraffin hardened, the plasticine was taken off and the stones were separated leaving a mass of paraffin that had the shape and size of the void space.

Determination of the Volume of Individual Fraction after the Los Angeles Abrasive Test

After the stone samples were subjected to the Los Angeles abrasive test, the volume of the individual fractions, between the $\frac{1}{2}$ inch sieve and the No. 12 sieve, that constituted the fine material was determined by placing the individual fraction in a graduate cylinder and the reading of the volume was obtained. Afterwards, the three fractions of stone were placed in a graduate cylinder, the contents shaken and the total volume of small material was read off from the graduate cylinder. The reading in cubic centimeters was reduced to cubic inches in order to use the English measuring system.

Presentation of Data

Test Results of Total Volume, Volume of Voids and Volume of Individual Fractions Determinations

A sample of stone from the Eli Lilly Waste Treatment Plant with sizes ranging from retained on the 3-inch sieve to retained on the 1½-inch sieve was used to collect the necessary data.

After the individual sizes of stone were subjected to the Los Angeles test without abrasive charge at 500 revolutions, the total volume of the larger pieces of stone (3/4 inch) and the volume of voids was determined by the procedures outlined before. Also after each abrasive test, the resulting material was subjected to a complete sieve analyses and the volume of the individual fractions between retained on the ½-inch sieve and retained on the No. 12 sieve were measured. The results of the total volume determinations are presented in Tables XXXI through XXXIV. The results of the void volume determination are presented in Tables XXXV through XXXVIII. The results for the sieve analyses and the determination of the volume of individual fractions and the results of the total volume of voids determinations are presented in Tables XXXIX through XLII.

Table XXXI

Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 3-inch sieve

Run No.	Sample A d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)	Sample B d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)
1	1.36	1.32	.68	40.9	1.39	1.35	.65	39.1
2	1.36	1.32	.68	40.9	1.34	1.30	.70	42.1
3	1.39	1.35	.65	39.1	1.41	1.37	.63	37.9
4	1.40	1.36	.64	38.5	1.36	1.32	.68	40.9
5	1.38	1.34	.66	39.7	1.35	1.31	.69	41.5
6	1.35	1.31	.69	41.5	1.34	1.30	.70	42.1
7	1.40	1.36	.64	38.5	1.36	1.32	.68	40.9
8	1.38	1.34	.66	39.7	1.35	1.31	.69	41.5
9	1.41	1.37	.63	37.9	1.38	1.34	.66	39.7
10	1.37	1.33	.67	40.3	1.32	1.28	.72	43.3
Ave.				39.70				40.90

Total Volume Sample A = 39.70 in^3
= .022 cu.ft.

Total Volume Sample B = 40.90 in^3
= .022 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXII

Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 2½-inch sieve

Run No.	Sample A d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)	Sample B d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)	Sample C d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)
1	1.53	1.49	.51	30.7	1.54	1.50	.50	30.1	1.47	1.43	.57	34.3
2	1.48	1.44	.56	33.7	1.46	1.42	.58	34.9	1.47	1.43	.57	34.3
3	1.46	1.42	.58	34.9	1.56	1.52	.48	28.9	1.53	1.49	.51	30.7
4	1.51	1.47	.53	31.9	1.50	1.46	.54	32.5	1.51	1.47	.53	31.9
5	1.50	1.46	.54	32.5	1.50	1.46	.54	32.5	1.48	1.44	.56	33.7
6	1.50	1.46	.54	32.5	1.46	1.42	.58	34.9	1.50	1.46	.54	32.5
7	1.47	1.43	.57	34.3	1.47	1.43	.57	34.3	1.50	1.46	.54	32.5
8	1.49	1.45	.55	33.1	1.47	1.43	.57	34.3	1.51	1.47	.53	31.9
9	1.50	1.46	.54	32.5	1.49	1.45	.55	33.1	1.53	1.49	.51	30.7
10	1.56	1.52	.48	28.9	1.45	1.41	.59	35.5	1.50	1.46	.54	32.5
Ave.				32.40				33.10				32.50

Total volume sample A = 32.40 in^3
= .019 cu.ft.

Total volume sample B = 33.10 in^3
= .019 cu.ft.

Total volume sample C = 32.50 in^3
= 0.19 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXIII

Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 2 -inch sieve

Run No.	Sample A d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)	Sample B d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)
1	1.57	1.53	.47	28.3	1.55	1.51	.49	29.5
2	1.56	1.52	.48	28.9	1.52	1.48	.52	31.3
3	1.50	1.46	.54	32.5	1.50	1.46	.54	32.5
4	1.52	1.48	.52	31.3	1.49	1.45	.55	33.1
5	1.53	1.49	.51	30.7	1.49	1.45	.55	33.1
6	1.51	1.47	.53	31.9	1.57	1.53	.47	28.3
7	1.53	1.49	.51	30.7	1.55	1.51	.49	29.5
8	1.53	1.49	.51	30.7	1.51	1.47	.53	31.9
9	1.52	1.48	.52	31.3	1.52	1.48	.52	31.3
10	1.52	1.48	.52	31.3	1.51	1.47	.53	31.9
Ave.				30.76				31.14

Total volume sample A = 30.76 in^3
= .018 cu.ft.
Total volume sample B = 31.14 in^3
= .018 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXIV

Total Volume Determination of Stone after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 1½-inch sieve

Run No.	Sample A d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)	Sample B d(ft) (1)	d-.04' (2)	D(ft) (3)	V(in^3) (4)
1	1.60	1.56	.44	26.5	1.59	1.55	.45	27.1
2	1.56	1.52	.48	28.9	1.55	1.51	.49	29.5
3	1.59	1.55	.45	27.1	1.52	1.48	.52	31.3
4	1.58	1.54	.46	27.7	1.56	1.52	.48	28.9
5	1.58	1.54	.46	27.7	1.54	1.50	.50	30.1
6	1.55	1.51	.49	29.5	1.53	1.49	.51	30.7
7	1.61	1.57	.43	2.59	1.51	1.47	.53	31.9
8	1.60	1.56	.44	26.5	1.57	1.53	.47	28.3
9	1.56	1.52	.48	28.9	1.56	1.52	.48	28.9
10	1.57	1.53	.47	28.3	1.57	1.53	.47	28.3
Ave.				27.70				29.50

Total Volume sample A = 27.70 in^3
= .016 cu.ft.

Total volume sample B = 29.50 in^3
= .017 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXV

Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 3-inch sieve

	Sample A	Sample B
wt. pan + 8" pipe =	2,728 gr	2,728 gr
wt. pan + pipe + stone =	7,791 gr	7,655 gr
wt. pan + pipe + stone + sand =	7,483 gr	7,345 gr
	7,472 gr	7,340 gr
	7,478 gr	7,331 gr
	7,481 gr	7,335 gr
	7,479 gr	7,335 gr
	7,477 gr	7,341 gr
	7,484 gr	7,343 gr
	7,480 gr	7,336 gr
	7,475 gr	7,336 gr
	7,481 gr	7,338 gr
Average	7,479 gr	7,338 gr

7,791 gr
- 7,479 gr
wt. sand = 312 gr = .689 lbs

vol. voids in sample A = $\frac{.689 \text{ lbs}}{95 \text{ lbs/cu.ft.}}$
= .00725 cu.ft.

7,655
- 7,338
wt. sand = 317 gr = .699 lbs

vol. of voids in sample B = $\frac{.699}{95}$
= .00737 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXVI

Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 2½-inch sieve

	Sample A	Sample B	Sample C
wt. pan + 8" pipe =	2,728 gr	2,728 gr	2,728 gr
wt. pan + pipe + stone =	7,852 gr	7,858 gr	7,691 gr
wt. pan + pipe + stone + sand =	7,625 gr	7,622 gr	7,437 gr
	7,628 gr	7,617 gr	7,430 gr
	7,632 gr	7,618 gr	7,442 gr
	7,635 gr	7,615 gr	7,435 gr
	7,629 gr	7,625 gr	7,433 gr
	7,630 gr	7,621 gr	7,435 gr
	7,637 gr	7,620 gr	7,439 gr
	7,623 gr	7,625 gr	7,431 gr
	7,624 gr	7,627 gr	7,435 gr
	7,627 gr	7,620 gr	7,433 gr
Average	7,629 gr	7,621 gr	7,435 gr

Sample A	Sample B	Sample C
7,852 gr	7,858 gr	7,691 gr
- 7,629 gr	- 7,621 gr	- 7,435 gr
wt. sand = 223 gr	wt. sand = 237 gr	wt. sand = 256 gr
= .492 lbs	= .523 lbs	= .564 lbs

Vol. voids in sample A = $\frac{.492}{95}$ = .00518 cu.ft.

Vol. voids in Sample B = $\frac{.523}{95}$ = .00550 cu.ft.

Vol. voids in Sample C = $\frac{.564}{95}$ = .00593 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXVII

Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 2-inch sieve

	Sample A	Sample B
wt. pan + 8" pipe =	2,728 gr	2,728 gr
wt. pan + pipe + stone =	7,640 gr	7,836 gr
wt. pan + pipe + stone + sand =	7,429 gr	7,630 gr
	7,422 gr	7,621 gr
	7,426 gr	7,620 gr
	7,423 gr	7,628 gr
	7,425 gr	7,625 gr
	7,427 gr	7,623 gr
	7,425 gr	7,624 gr
	7,426 gr	7,629 gr
	7,422 gr	7,621 gr
	7,425 gr	7,619 gr
Average	7,425 gr	7,624 gr

	7,640 gr
-	7,425 gr
wt. of sand =	215 gr
	= .474 lbs

	7,836 gr
-	7,624 gr
wt. of sand =	212 gr
	= .466 lbs

Vol. voids in Sample A $= \frac{.474}{95}$

= .00499 cu.ft.

Vol. voids in Sample B $= \frac{.466}{95}$

= .00491 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXVIII

Determination of Volume of Voids after the Los Angeles Test without Abrasive Charge at 500 Revolutions

Initial size of stone: retained on 1½-inch sieve

	Sample A	Sample B
wt. pan + 8" pipe =	2,728 gr	2,728 gr
wt. pan + pipe + stone =	7,939 gr	7,801 gr
wt. pan + pipe + stone + sand =	7,740 gr	7,588 gr
	7,745 gr	7,598 gr
	7,748 gr	7,599 gr
	7,741 gr	7,602 gr
	7,744 gr	7,590 gr
	7,745 gr	7,592 gr
	7,742 gr	7,594 gr
	7,739 gr	7,593 gr
	7,740 gr	7,589 gr
	7,742 gr	7,595 gr
Average	7,744 gr	7,594 gr

Sample A:

7,939 gr
- 7,744 gr
wt. sand = 195 gr
= .440 lbs

Sample B:

7,801 gr
- 7,594 gr
wt. sand = 207 gr
= .457 lbs

Vol. voids in Sample A = $\frac{.440}{95}$
= .00463 cu.ft.

Vol. voids in Sample B = $\frac{.457}{95}$
= .00481 cu.ft.

Source of sample: Eli Lilly Waste Treatment Plant

Table XXXIX

Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 3-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction passing	Stone Fraction retained	Sample A wt.(gr)	Sample A (%)	Sample A V.(in^3)	Sample B wt.(gr)	Sample B (%)	Sample B V.(in^3)
3 1/2	3	2437	48		2260	46	
3	2 1/2	945	19		641	13	
2 1/2	2	437	9		893	18	
2	1 1/2	291	6		283	6	
1 1/2	1	248	5		182	4	
1	3/4	38	1		52	1	
3/4	1/2	7	0		65	1	
1/2	# 4	15	0	0.73	12	0	0.58
# 4	# 6	0	0	0	41	1	1.83
# 6	#12	21	0	1.04	27	0	1.28
#12	Pan	624	12		471	10	
Totals		5063	100	0.89	4927	100	0.73
Total Volume (cu.ft.)			.023			.023	
Volume of voids (cu.ft.)			.00725			.00737	

Source of sample: Eli Lilly Waste Treatment Plant (new stone)

Table XL

Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 2½-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction passing	Stone Fraction retained	Sample A wt.(gr)	Sample A (%)	Sample A V.(in^3)	Sample B wt.(gr)	Sample B (%)	Sample B V.(in^3)	Sample C wt.(gr)	Sample C (%)	Sample C V.(in^3)
3	2 1/2	2253	44		2455	48		2384	48	
2 1/2	2	2000	39		1510	29		1731	35	
2	1 1/2	261	5		596	12		297	6	
1 1/2	1	0	0		0	0		0	0	
1	3/4	0	0		31	1		0	0	
3/4	1/2	0	0		26	0		0	0	
1/2	# 4	7	0	0.40	10	0	0.58	8	0	0.46
# 4	# 6	2	0	0.12	0	0	0	12	0	0.67
# 6	#12	5	0	0.27	12	0	0.67	8	0	0.40
#12	Pan	596	12		490	10		523	11	
Totals		5124	100	0.58	5130	100	0.60	4963	100	0.61
Total volume (cu.ft.)			.019			.019			.019	
Volume of voids (cu.ft.)			.00518			.00550			.00593	

Source of sample: Eli Lilly Waste Treatment Plant (new stone)

Table XLI

Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 2-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction passing	retained	Sample A wt.(gr)	(%)	V.(in^3)	Sample B wt.(gr)	(%)	V.(in^3)
2 1/2	2	2390	49		2546	50	
2	1 1/2	1097	22		1289	25	
1 1/2	1	782	16		711	14	
1	3/4	19	0		10	0	
3/4	1/2	45	1		0	0	
1/2	# 4	21	1	1.01	3	0	0.15
# 4	# 6	20	0	1.01	6	0	0.30
# 6	#12	18	0	0.85	4	0	0.21
#12	Pan	520	11		539	11	
Totals		4912	100	1.23	5108	100	0.24
Total volume (cu.ft.)			.018			.018	
Volume of voids (cu.ft.)			.00499			.00491	

Source of sample: Eli Lilly Waste Treatment Plant (new stone)

Table XLII

Sieve Analyses, Total Volume of Sample, Volume of Voids and Volume of Fractions of Stone Initially Retained on the 1½-Inch Sieve after the Los Angeles Test without the Abrasive Charge at 500 Revolutions

Stone Fraction passing	Stone Fraction retained	Sample A wt.(gr)	Sample A (%)	Sample A V.(in^3)	Sample B wt.(gr)	Sample B (%)	Sample B V. (in^3)
2	1 1/2	2612	51		2521	50	
1 1/2	1	1195	39		1920	38	
1	3/4	13	0		49	1	
3/4	1/2	18	0		8	0	
1/2	# 4	9	0	0.46	27	1	1.34
# 4	# 6	13	0	0.55	16	0	0.79
# 6	#12	20	0	0.88	18	0	0.76
#12	Pan	531	10		514	10	
Totals		5211	100	0.62	5073	100	1.41
Total volume (cu.ft.)			.016			.017	
Volume of voids (cu.ft.)			.00463			.00481	

Source of sample: Eli Lilly Waste Treatment Plant (new stone)

Results of the Measurement of Stones and Void Spaces

Stones from the Eli Lilly Waste Treatment Plant of the following sizes: retained on 3, 2½, 2 and 1½ inch sieves, were used to obtain the sizes of stones and void spaces before and after the Los Angeles test without abrasive charge at 500 revolutions by the procedure outlined before.

Two samples of each of the stones retained on 3, 2 and 1½ inch sieves were used to obtain the size of the stone and void spaces before the abrasion test and two other samples of each of the same sizes were used to obtain the sizes of stone and void spaces after the abrasive tests. Three samples of stone retained on the 2½ inch sieve were used to obtain the size of stone and void spaces before the abrasion test and three other samples of the same size were used to obtain the sizes of stone and void spaces after the abrasion test. The measurements of the three axis of the stones and void spaces before and after the abrasive test are presented in Tables XLIII through XLVI.

Table XLIII

Dimensions of 3 Inch Stone and Void Spaces

Original stone sample from Eli Lilly Waste Treatment Plant

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	2.50	3.60	3.60	1.10	1.90	1.90
	2.00	3.70	2.90	.95	2.30	1.50
	2.10	3.20	2.90	1.00	2.00	1.65
	2.00	3.60	3.40	1.00	2.55	1.80
	2.30	4.20	3.00	.80	2.30	1.70
	2.70	4.50	3.10	.85	1.95	1.70
	2.40	4.00	3.70	.70	2.40	1.85
	2.40	4.30	4.10	1.20	2.30	1.75
	2.00	3.70	3.40	1.00	2.50	1.50
	2.20	4.10	3.20	.95	2.00	1.65
	2.80	4.00	3.30	1.15	2.10	1.60
	2.80	3.50	3.00	1.05	2.05	1.55
	2.50	3.30	2.90	.90	2.45	1.80
	2.20	3.40	3.10	.95	2.50	1.75
	2.00	3.80	2.80	1.00	2.60	1.60
	2.30	3.90	3.20	.85	1.95	1.70
	2.50	3.60	3.40	.90	2.00	1.50
	2.70	3.80	3.30	1.05	2.25	1.50
	2.40	3.80	3.10	.80	2.30	1.55
	2.40	4.00	3.60	.75	2.10	1.85
Averages	2.36	3.80	3.25	.95	2.23	1.67

Table XLIII (cont.)

Dimensions of 3 Inch Stone and Void Spaces

Sample from Eli Lilly Waste Treatment Plant
after abrasion in the Los Angeles Testing Machine
without abrasive charge

	Stone Dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	1.90	3.45	2.75	.90	1.85	1.45
	1.85	3.30	2.90	.60	1.65	1.10
	2.00	3.65	2.35	.55	1.50	1.35
	2.20	3.80	2.95	.75	1.90	1.60
	1.75	3.10	2.80	1.00	1.80	1.50
	2.10	3.35	3.10	.85	2.00	1.70
	2.05	3.50	2.85	.95	2.05	1.30
	2.05	3.55	2.50	1.05	1.95	1.40
	1.95	3.25	2.90	.75	1.75	1.50
	1.80	4.05	2.65	.60	1.80	1.35
	1.90	3.70	3.40	.80	2.10	1.65
	1.80	3.50	2.75	.65	1.70	1.20
	2.00	3.50	3.05	.95	1.70	1.40
	2.10	3.35	2.95	1.00	1.60	1.55
	2.30	3.85	2.80	1.10	1.85	1.50
	1.90	3.90	2.80	1.25	1.90	1.25
	1.80	3.75	3.00	.80	1.55	1.20
	2.00	3.95	2.70	.70	2.00	1.60
	1.95	3.20	2.55	.95	1.70	1.35
	2.15	3.40	2.90	.50	1.85	.155
Averages	1.98	3.56	2.83	.83	1.81	1.43

Table XLIV

Dimensions of 4½ Inch Stone and Void Spaces

Original stone sample from Eli Lilly Waste Treatment Plant

	Stone dimensions (in)			Void space dimensions (in)		
Axis No.	1	2	3	1	2	3
	2.55	3.50	2.85	1.00	1.95	1.50
	1.50	3.10	2.90	.70	1.75	1.58
	2.30	3.95	2.40	.90	2.35	1.17
	2.30	3.30	2.95	.95	2.10	1.30
	2.25	3.05	2.35	.25	2.60	1.28
	1.80	3.40	2.85	.38	1.70	1.30
	2.15	3.10	2.45	.70	1.28	1.00
	2.15	3.30	3.00	.70	1.50	1.15
	1.90	3.50	2.70	.95	2.93	1.20
	2.20	3.35	2.70	.56	2.10	1.45
	1.55	4.05	2.25	.45	1.63	1.13
	1.90	3.55	2.70	.81	1.90	1.22
	2.20	3.30	2.45	.93	1.95	1.36
	2.00	4.05	3.15	1.05	2.43	1.68
	1.70	3.45	2.65	.67	1.57	1.05
	1.55	4.15	2.85	.30	1.15	.90
	2.30	4.25	3.35	.70	2.10	1.70
	1.85	4.05	2.25	.82	1.70	1.70
	2.40	4.90	2.75	.25	2.20	1.40
	2.00	3.35	2.80	.75	1.60	1.30
	2.20	3.90	2.75	.55	2.15	1.35
	1.90	4.15	3.15	.20	2.20	1.80
	1.90	3.60	3.60	.60	2.55	1.75
	2.40	3.80	2.50	.73	1.70	1.50
	1.60	4.30	2.35	.85	1.95	1.45
	1.90	4.10	2.85	.87	1.90	1.67
	2.20	3.60	2.85	.95	2.15	1.82
	2.05	3.30	2.40	.90	2.55	1.97

Table XLIV (cont.)

Axis No.	Stone dimensions (in)			Void space dimensions (in)		
	1	2	3	1	2	3
	2.40	3.65	3.15	1.05	2.30	1.90
	2.30	3.75	3.35	.95	1.90	1.35
	1.80	3.85	3.00	.20	1.95	1.90
	1.70	4.20	3.55	.50	1.80	1.55
	1.60	3.90	3.25	.90	2.40	1.20
	1.70	3.30	2.90	.85	2.45	1.45
	1.75	3.98	3.15	.70	2.35	1.45
	1.95	2.85	2.50	.95	1.80	1.65
	1.50	4.35	2.90	.80	2.70	2.00
	2.90	4.10	2.90	.45	1.90	1.70
	1.80	3.65	2.10	.70	2.05	1.50
	2.30	3.80	3.10	.75	2.50	1.80
	2.40	3.00	2.40	.55	2.50	2.00
	1.80	3.50	3.15	.95	3.65	2.25
	2.40	2.45	2.40	.90	3.20	2.05
	1.55	3.80	3.10	.60	2.85	1.85
	1.70	3.40	3.00	.90	2.90	1.90
	1.80	4.05	2.90	.40	2.20	1.70
	2.48	2.90	2.78	.80	2.85	2.00
	1.60	3.40	3.05	.85	3.15	2.25
	1.95	3.05	3.05	1.10	2.90	2.05
	1.80	3.00	2.75	.50	1.90	1.10
	2.50	2.80	2.60			
	1.45	2.75	2.55			
	2.30	3.50	2.95			
	1.75	4.00	2.80			
	1.65	4.00	3.25			
	1.50	4.15	3.00			
	2.05	2.90	2.80			
	2.06	3.10	2.80			
	1.60	3.20	2.85			

Table XLIV (cont.)

Axis No.	Stone dimensions (in) 1	2	3	Void space dimensions (in) 1	2	3
	1.95	4.10	2.60			
	2.40	3.45	2.85			
	1.70	3.25	3.25			
	1.85	4.25	2.95			
	2.25	4.05	3.50			
	2.40	3.80	3.25			
	2.05	2.95	2.60			
	1.70	2.80	2.50			
	1.85	3.40	2.55			
	1.05	2.70	2.20			
	1.50	3.05	2.70			
	1.35	4.30	3.10			
	1.80	2.50	2.35			
	1.90	3.45	2.50			
	1.55	3.00	2.25			
	2.15	2.75	2.40			
	1.90	3.80	3.10			
	2.00	4.10	3.35			
	1.75	2.80	3.10			
	1.70	2.80	2.45			
	1.45	3.80	2.90			
	1.90	2.95	2.25			
	1.70	3.25	2.00			
	1.70	3.50	2.75			
	2.20	4.10	3.00			
	1.55	3.05	2.15			
	2.10	4.05	3.45			
	2.35	4.30	3.90			
	1.75	2.80	2.20			
Averages	1.93	3.53	2.80	.72	2.20	1.56

Table XLIV (cont.)

Dimensions of 2½ Inch Stone and Void Spaces

Sample from Eli Lilly Waste Treatment Plant
after abrasion in the Los Angeles abrasion machine
without abrasive charge

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	1.20	3.60	2.40	.50	1.80	1.50
	1.85	3.50	2.65	.70	1.10	1.10
	1.60	3.40	2.70	.80	1.75	1.40
	2.20	3.15	2.30	.65	1.80	1.50
	1.65	3.70	2.60	.75	1.65	1.35
	2.10	3.55	2.10	.60	1.95	1.40
	2.25	3.30	2.50	.90	1.90	1.50
	1.35	3.40	2.65	.95	1.85	1.45
	1.65	3.20	2.80	.80	1.60	1.25
	1.60	3.75	2.90	.85	1.50	1.10
	2.25	3.60	3.05	.70	1.85	1.45
	2.35	2.85	2.35	.70	1.75	1.50
	1.85	3.20	2.85	.75	1.60	1.30
	1.90	3.35	1.90	.50	1.50	1.20
	1.55	3.80	2.50	.40	1.55	1.15
	2.15	3.25	3.05	.55	1.90	1.00
	1.35	3.25	2.45	.65	2.00	1.05
	2.55	3.75	2.55	.75	2.05	1.65
	2.20	3.80	2.85	.80	1.90	1.20
	2.05	3.15	2.30	.70	1.75	1.15
	1.40	3.45	3.00	.35	1.45	1.10
	1.80	3.70	2.90	.60	1.80	1.45
	2.25	3.10	2.95	.85	1.50	1.20
	2.25	3.60	2.60	.75	2.10	1.65
	1.65	3.85	2.95	.80	1.45	1.05
	1.40	2.85	2.75	.90	1.75	1.20

Table XLIV (cont.)

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	1.80	3.35	2.55	.45	1.90	1.00
	1.15	2.50	2.00	.50	1.50	1.15
	.75	2.20	2.00	.95	1.50	1.45
	1.60	2.95	2.60	.70	1.45	1.45
	1.55	2.55	2.10	.55	1.35	1.10
	1.30	2.80	2.80	.70	1.50	1.50
	1.95	2.60	2.50	.60	1.95	1.30
	2.00	4.25	2.50	.80	1.00	1.00
Averages	1.78	3.30	2.58	.69	1.68	1.29

Table XLV

Dimensions of 2 Inch Stone and Void Spaces

Original Stone Sample from Eli Lilly Waste Treatment Plant

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	1.50	3.30	2.90	.55	2.00	1.40
	1.80	2.90	2.80	.30	1.55	1.50
	1.50	3.40	3.10	.75	1.95	1.35
	1.80	3.30	1.80	.60	1.80	1.30
	1.00	3.00	2.90	.65	2.10	1.50
	1.30	3.00	2.30	.50	2.05	1.40
	1.50	3.20	3.00	.50	1.85	1.35
	2.00	4.00	2.30	.45	1.70	1.45
	2.00	4.00	2.80	.80	1.90	1.60
	1.30	4.70	2.40	.75	1.90	1.30
	2.00	3.30	2.20	.65	1.75	1.40
	1.60	3.50	2.80	.55	1.80	1.45
	1.60	3.20	2.50	.80	1.85	1.25
	1.20	3.00	2.90	.70	1.60	1.60
	1.50	4.10	3.00	.70	1.60	1.45
	2.00	4.40	2.20	.65	1.50	1.10
	1.80	3.70	2.00	.45	1.95	1.40
	1.40	3.60	2.60	.80	2.00	1.35
	1.50	3.10	2.30	.85	1.90	1.20
	1.30	3.90	2.80	.75	2.05	1.05
Averages	1.58	3.53	2.58	.64	1.84	1.37

Table XLV (cont.)

Dimensions of 2 Inch Stone and Void Spaces

Sample from Eli Lilly Waste Treatment Plant
after abrasion in the Los Angeles testing machine
without abrasive charge

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	1.55	3.00	2.40	.55	1.50	1.05
	1.30	2.85	2.55	.70	1.35	1.20
	1.70	2.95	2.30	.45	1.45	1.00
	1.45	3.10	2.75	.60	1.30	.90
	1.50	3.00	2.70	.65	1.75	.90
	1.70	2.90	2.25	.50	1.60	.80
	1.35	2.55	2.40	.30	1.50	.95
	1.40	2.75	2.50	.45	1.55	1.20
	1.40	3.05	2.65	.45	1.55	1.00
	1.60	3.00	2.35	.90	1.35	.95
	1.75	2.80	2.35	.55	1.65	1.05
	1.25	3.00	2.45	.70	1.40	.85
	1.45	2.95	2.10	.25	1.35	.70
	1.80	3.35	2.30	.50	1.45	1.00
	1.50	2.60	2.40	.30	1.80	1.20
	1.30	2.85	2.55	.45	1.50	.90
	1.65	2.70	2.70	.65	1.40	1.05
	1.45	2.95	2.35	.60	1.10	.75
	1.70	3.00	2.25	.50	1.35	.80
	1.75	2.90	2.80	.45	1.30	1.00
Averages	1.53	2.91	2.46	.52	1.46	.96

Table XLVI

Dimensions of 1¼ Inch Stone and Void Spaces

Original stone sample from Eli Lilly Waste Treatment Plant

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	2.00	2.00	2.00	.45	1.85	1.35
	1.30	2.60	2.50	.70	1.80	1.10
	1.50	3.20	1.90	.50	1.70	1.30
	1.70	2.60	2.10	.65	1.90	1.50
	1.60	3.00	1.60	.80	2.00	1.45
	1.30	4.60	1.30	.30	1.50	.95
	1.20	2.80	2.20	.35	1.80	1.10
	1.40	2.90	2.40	.40	1.75	1.25
	1.00	3.40	1.80	.40	1.60	1.60
	1.60	2.90	2.10	.55	1.55	1.35
	1.60	3.60	2.10	.70	1.40	1.00
	1.50	4.00	1.90	.60	1.70	1.15
	1.70	3.10	1.70	.40	1.70	1.10
	1.50	2.50	2.50	.45	1.85	1.30
	1.50	2.70	2.10	.60	1.90	1.55
	1.80	3.70	2.70	.65	1.95	1.40
	1.20	3.20	2.10	.35	2.10	1.35
	1.40	3.40	2.90	.50	1.65	1.35
	1.90	2.90	2.50	.65	2.00	1.25
	1.50	2.90	2.30	.40	2.05	1.40
Averages	1.51	3.10	2.14	.52	1.79	1.2y

Table XLVI (cont.)

Dimension of 1½ Inch Stone and Void Spaces

Sample from Eli Lilly Waste Treatment Plant
after abrasion in the Los Angeles testing machine
without abrasive charge

	Stone dimensions (in)			Void spaces dimensions (in)		
Axis No.	1	2	3	1	2	3
	1.40	2.80	2.25	.30	1.40	1.00
	1.20	2.95	2.00	.50	1.65	.90
	1.35	2.55	2.40	.20	1.30	1.10
	1.60	2.75	2.35	.45	1.35	1.35
	1.50	2.60	2.20	.35	1.50	1.00
	1.00	3.00	2.05	.40	1.40	.75
	1.25	2.80	2.50	.30	1.60	.95
	1.45	2.90	2.45	.30	1.45	1.05
	1.55	2.90	2.30	.25	1.45	.80
	1.40	2.70	2.05	.50	1.20	.80
	1.30	2.85	2.10	.20	1.30	.90
	1.45	2.65	1.90	.40	1.50	1.05
	1.45	2.50	2.25	.35	1.45	.95
	1.00	2.95	2.35	.30	1.35	.75
	1.70	2.80	2.50	.45	1.40	1.00
	1.50	3.00	2.70	.20	1.40	1.05
	1.40	3.05	2.20	.20	1.55	.80
	1.20	3.20	2.10	.35	1.30	.60
	1.00	2.75	2.25	.60	1.45	1.45
	1.45	3.10	2.30	3.0	1.70	1.00
Averages	1.36	2.84	2.26	.35	1.44	.96

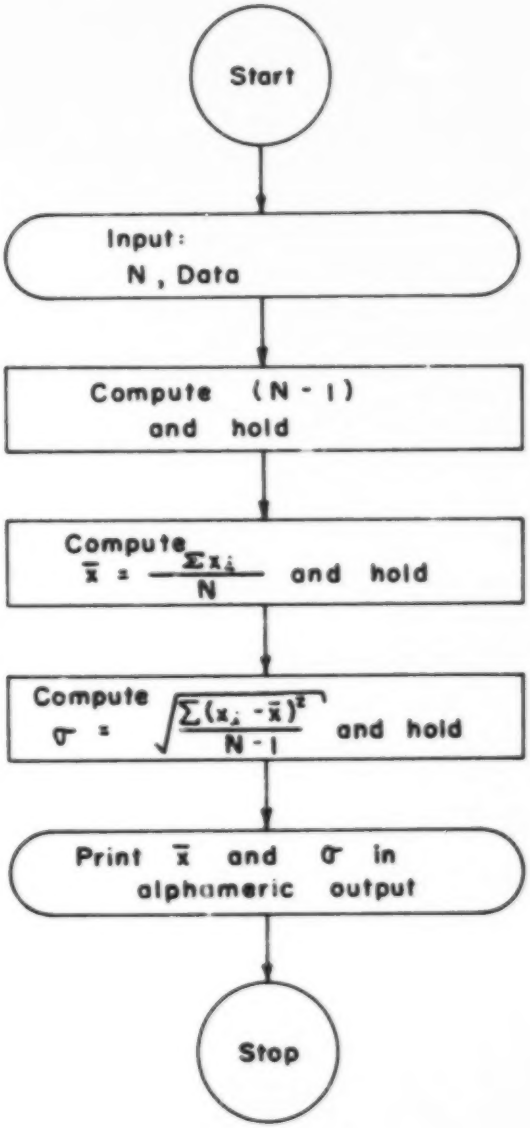
Statistical Analyses of Data

The data obtained from the measurements of the three axis of the stone and void spaces had to be statistically analysed to observe if there is a relation between the sizes of stone and void spaces. This analysis included the computation of the mean and standard deviation for sets of N numbers and the computation of the correlation coefficients for pairs of N numbers. Therefore, consideration was given to the solution of these computations with the aid of a digital computer.

In the solution of a problem by the use of a digital computor, a flow diagram is used to show clearly what operations are desired for the machine to perform. This flow diagram or chart consists of labeled boxes of various symbolic shapes connected together by direct lines. In this study two programs were used, one for the calculations of the mean and standard deviation of N points or numbers (Figure 7) and another for the calculation of the correlation coefficient of N pairs of numbers (Figure 8).

A description of the computer is presented in Appendix B. Both programs are presented in Appendix C and Appendix D. The use of this electronic computational procedure resulted in a great saving element in the calculations of the mean, standard deviations and correlation coefficients.

A tabulation of the results of the statistical analyses of the data obtained for the measurements of stones and void spaces is presented in Tables XLVII through L.



Flow Diagram for the Computation of the Mean and Standard Deviation of N Numbers or Points.

Fig. 7

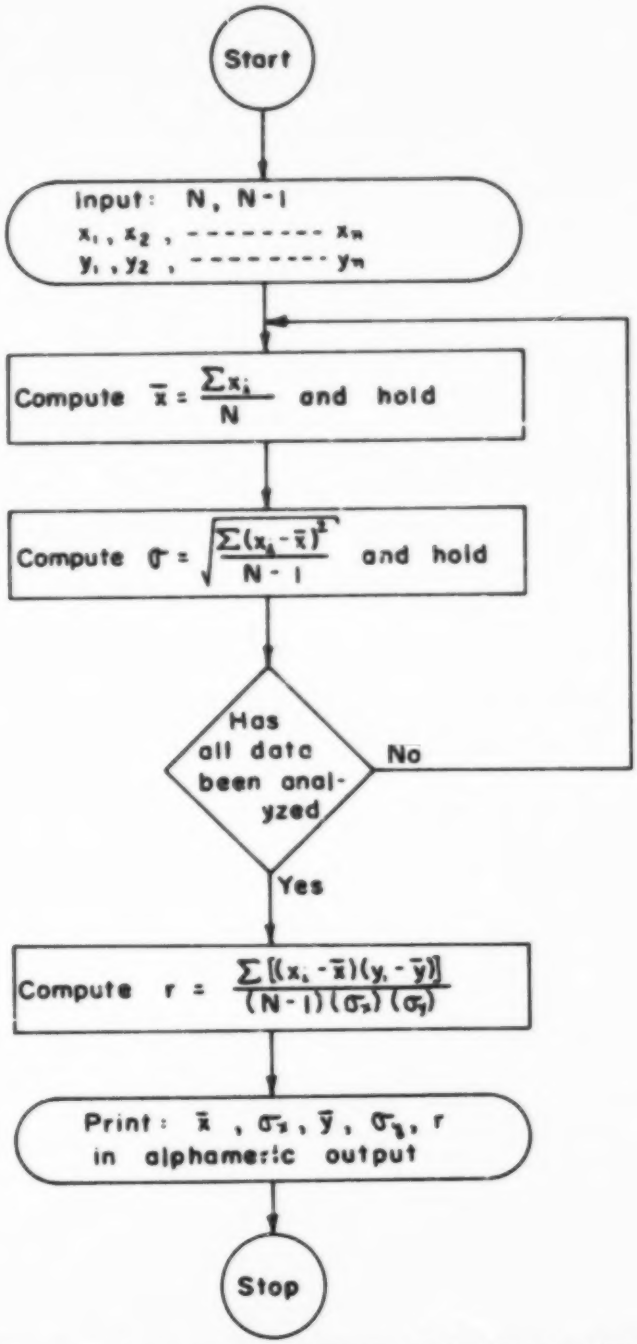

Start
input: N, N-1
$x_1, x_2, \dots x_n$
$y_1, y_2, \dots y_n$
Compute $\bar{x} = \frac{\sum x_i}{N}$ and hold
Compute $\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N-1}}$ and hold
Has all data been analyzed
No
Yes
Compute $r = \frac{\sum [(x_i - \bar{x})(y_i - \bar{y})]}{(N-1)(\sigma_x)(\sigma_y)}$
Print: $\bar{x}$, σ_x, $\bar{y}$, σ_y, r in alphameric output
Stop

Fig. 8 Flow Diagram for the Computation of Mean, Standard Deviation and Correlation Coefficient of N Pairs of Numbers or Points

Table XLVII

Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 3½ Inch Stones and of the Void Spaces between the Stones

		Stone		Void spaces		
	Dimension No.	mean (in)	standard deviation	mean (in)	standard deviation	correlation coefficient
Before test	1	2.36000000	.26437612	.94749998	.13126409	+.11071362
	2	3.80000000	.33403434	2.22500000	.22623927	-.18107590
	3	3.25000000	.32525294	1.67000000	.13018205	+.40397773
After test	1	1.97750000	.146442673	.83499999	.20006577	+.15405909
	2	3.55500000	.26700088	1.81000000	.16670175	+.22644479
	3	2.83250000	.22957339	1.42500000	.16343355	+.35945745

Table XLVIII

Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 3 Inch Stone and the Void Spaces between the Stones

		Stone		Void spaces	
	Dimension No.	mean (in)	standard deviation	mean (in)	standard deviation
Before test	1	1.9345454	.33238914	.71639999	.24750509
	2	3.5321589	.52156802	2.19780000	.82391758
	3	2.7952272	.38519132	1.56560000	.33996043
After test	1	1.7794118	.36990024	.69117648	.18342708
	2	3.3029412	.44855681	1.6750000	.25621073
	3	2.5779412	.40173138	1.2882353	.19386766

Table XLIX

Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 2½ Inch Stone and the Void Spaces between the Stone

		Stones		Void spaces		
	Dimension No.	mean (in)	standard deviation	mean (in)	standard deviation	correlation coefficient
Before test	1	1.5800000	.29307803	.63749999	.14678573	-.26915470
	2	3.5300000	.50689975	1.84000000	.17591864	-.16762193
	3	2.5800000	.37219123	1.37000000	.14363696	+.32783723
After test	1	1.5275000	.16973276	.52499999	.15432365	+.00753492
	2	2.9125000	.17908760	1.46000000	.16431676	-.31299476
	3	2.4550000	.18980599	.96249999	.14315523	+.35108096

Table L

Tabulation of the Results of the Statistical Analysis of the Sizes of the Axis of 2 Inch Stone and the Void Spaces between the Stones

		Stones		Void spaces		
	Dimension No.	mean (in)	standard deviation	mean (in)	standard deviation	correlation coefficient
Before test	1	1.5100000	.24473400	.5199999	.14179302	+.44135719
	2	3.1000000	.57856445	1.7875000	.18978866	-.46014599
	3	2.1350000	.38563003	1.2900000	.17814836	+.16241628
After test	1	1.3575000	.19753413	.3450000	.11343906	-.20375632
	2	2.8400000	.18609561	1.4350000	.12471019	+.20296977
	3	2.2600000	.19574419	.96249999	.19793340	+.30564758

Discussion and Summary of Data

It can be observed from Table LI, a compilation of data from Tables XXXIX through XLII, that there is no appreciable difference in the percentage of void volume in the samples for the different sizes of stone after the abrasive test. Also the percent void volume filled with the small material is presented in the same Table for the different sizes of stones tested. It is observed that the void volume filled by the small material is between 6 and 12 percent, which would indicate that if the stone is handled with the severity of the Los Angeles abrasive test without abrasive charge at 500 revolutions, an appreciable amount of fines would be formed. Some of this material would be very fine and would not be expected to be retained in the voids of the larger stone if flushed with water or sewage.

The correlation coefficients between corresponding axis sizes of stones and void spaces before and after the abrasive test as shown in Tables XLVII, XLIX and L, indicate that there is no correlation between the average measurements of the axis of stones and void spaces since the values obtained for the coefficients are less than 1.0 which would be a perfect correlation between pairs of numbers. Furthermore, the signs of the coefficients are different, thus indicating that the sizes of the axis of the void spaces do not increase or decrease always as the stone axis sizes increase or decrease. Since there is no correlation between the axis for stones and void spaces before and after the abrasive test, the size of the void spaces depend only on the manner of packing of the stones.

Table LI

Tabulation of the Total Volume of Sample, Total Volume of Voids and Total Volume of Small Material for Different Sizes of Stone after the Abrasive Test

		Sizes of Stone			
		3	2½	2	1½
Ave. total volume of sample (ft^3)		0.023	0.019	0.018	0.0165
Ave. total volume of voids (ft^3)		0.00731	0.00554	0.00495	0.00472
Percent void volume in sample		32	29	28	29
Ave. total volume of small material	in^3	0.81	0.60	0.73	1.01
	ft^3	0.00047	0.00035	0.00042	0.00058
Percent void volume filled		6	6	9	12

Source of sample: Eli Lilly Waste Treatment Plant

FINAL SUMMARY

Although the two parts in which this study was divided were summarized before, a summary of the work done is persented to substantiate more clearly the findings.

When the results of the abrasive tests of all the samples of stone were converted to a common denominator there was no apparent significant difference in the ability of the stone to withstand abrasion, and it was not possible to differentiate between stone from trickling filters that had clogged and those that operated satisfactorially. This observation leads to the belief that clogging of trickling filters may not be attributed to the stone if it meets the present standards for stone quality.

The stone tested showed that under an intensive abrasive action there was considerable fracturing and formation of fines. It was observed that the amount of abraded material formed was not in direct relation to the severity with which the stone was handled (number of revolutions in the Los Angeles testing machine). The amount of fine material formed during the abrasive action was very much less when handled with less severity.

The study on sizes of stone and void spaces showed that the sizes of the void spaces were not in a direct relation to the size of the stone, therefore it would seem reasonable to believe that stone might be placed in such a manner as to have smaller void spaces. The extent of this observation was not determined in this study.

The amounts of fractured material or fines produced during the abrasive tests (dropping the stone 100 times a distance of 28 inches) did not produce enough fine material in a given volume of stone to materially decrease the void volume therein. It appears that it would be necessary to accumulate fines in certain parts of the filter bed in order to cause clogging of the filter when placed in operation.

The stone samples tested were not easily abraded and it would seem reasonable to conclude that if filter stone, of the quality used in these studies, was handled no more severely than dropping 100 times a distance of 28 inches each time and with no fines in the material prior to placing, the filter stone could be placed with most any equipment available. It is concieved that this information might provide a basis for developing methods of stone placement that are less costly than some methods presently in use.

CONCLUSIONS

1. Clogging of trickling filters may not be attributed to the stone if it meets the present standards for stone quality.

2. The stone when subjected to an abrasive action did not produce enough fine material in a given volume of stone to materially decrease the void volume.

3. The amount of abraded material produced during the abrasive action is not in direct relation to the severity with which the stone was handled.

4. The sizes of the void spaces do not depend on the size of the stone; it depends only on the manner of packing.

5. If prior to placement in the filter, the stone is free of fines, and if the stone is handled not more severely than dropping it 100 times a distance of 28 inches, the filter stone could be placed with most any equipment available.

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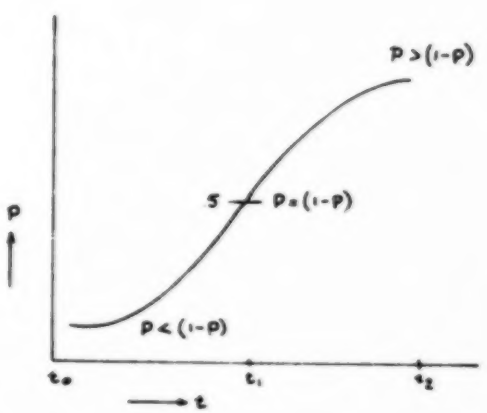
APPENDIX A

In order to convert the percent of loss in weight of the different stones tested to a common denominator using the couve for the loss in weight of a sample of stone at different number of revolutions (Figure 6), it was thought that a mathematical expression for the curve would be of importance.

Since the mathematical expression of the curve in Figure 6 could not be easily determined, the percentage of loss in weight (P) with respect to the amount lost at 500 revolutions had to be computed. These values of the percentage of loss in weight with respect to the amount lost at 500 revolutions are presented in Table LII as the "experimental values," and when plotted, a curve similar to the one shown in the following Figure is obtained.



The curve is of the following general mathematical form:

$$\frac{dP}{dt} = K\,P\,(1-P) \qquad (1)$$

Table LII

Experimental and Calculated Values of the Percentage of Loss in Weight with Respect to the Amount Lost at 500 Revolutions for Different Number of Revolutions

No. revolutions	"Experimental values" for "P"	Calculated values* for "P"
0	0	.0024
100	.068	.061
200	.341	.365
300	.865	.840
400	.980	.980
500	1.000	.998

* Values calculated with equation $P = \frac{1}{1 + e^{-.022\ (t-225)}}$

where, P is the percentage of loss in weight with respect to the amount of weight lost at 500 revolutions; t is the time element or number of revolutions; and k is a constant.

Equation (1) shows that when t = 0 the slope of the curve is zero since no abrasive action has taken place. As the number of revolutions (t) increases, the slope of the curve also increases up to a point when the weight of the material still retained on the initial sieve is 50 percent of the original weight (P = 1-P). The shape of the curve between to and t, is characterized by the fact that the loss in weight of the sample (P) is smaller than the amount of stone still retained on the initial sieve (1-P). When the number of revolutions increases from t_1 to t_2 the slope of the curve gradually becomes smaller, thus indicating that in this portion of the curve the loss in weight (P) is greater than the amount of stone still retained on the initial size sieve (1-P).

Integrating equation (1) the following expression is obtained:

$$P = \frac{1}{1 + e^{-k\,(t-a)}} \qquad (2)$$

where, t is the number of revolutions; "a" is the number of revolutions at which P is equal to 50 percent.

Equation (2) has two unknown constants k and a. The curve can be plotted as a straight line on a graph with a ordinate which has the following scale equation:

$$Y = M \ln \frac{P}{1-P}$$

where Y is a distance from the mid point of the ordinate (.5), and M is the scale modulus. From this plot, the constant "a", can be obtained as the number of revolutions at which P = 0.50.

When the experimental values of P, shown in Table LII are plotted as a straight line, the constant "a" was found to have a value of 225 revolutions. When the experimental data (t = 400; P = .98) is substituted in the equation the constant k is calculated to be 0.022. Thus equation (2) for the experimental values obtained, is:

$$P = \frac{1}{1 + e^{-0.022\,(t-225)}} \qquad (3)$$

which represents the equation of the curve for the loss in weight of the samples at different numbers of revolutions. The calculated values of P are shown in Table LII and it can be observed that they agree very closely with the experimental values. Thus the equivalent loss in weight of a stone sample can be computed from equation (3) by multiplying the loss in weight of the sample at 500 revolutions by the value of P at the desired number of revolutions t.

During the formulation of this equation, a possible way of defining the character of a stone sample was devised. From equation (2) the following relation can be derived,

$$K = \frac{\ln (P/1-P)}{t-a} \qquad (4)$$

The value of K in equation (4) could determine the characteristic of a stone siver, when a soft stone is tested the value of a is small and k is large, while for a hard stone the value of a is larger and k will be smaller.

APPENDIX B

Description of the Digital Computer

A digital computer is, basically, a device which is capable of processing numbers toward some desired result. The digital computer is composed essentially of an input device, a memory unit, an arithmetic unit, and an output device. Since this machine is only capable of performing the four basic arithmetic operations (addition, subtraction, multiplication and division), a step-by-step "program" of instructions is required to solve a problem.

The computer used in this study was the LGP-30. This machine can be defined as a general-purpose, automatically-sequenced, stored-program, electronic digital computer manufactured by the Royal McBee Corporation. The computer works with binary fractions, and the numbers have a fixed decimal point at the left end of the number. It uses an electrical typewriter (Flexowriter) and a paper tape reader and punch for input and output.

The Floating Point Interpretative System (H1-23.2) is a program written for the LGP-30 to enable it to understand an instruction code which is not its own basic language. The system is quite flexible and yet is very easy to program and operate. The program works with decimal numbers and the decimal point is not fixed in any one particular location in the number as the name of the system indicates.

The program carries out operations on these decimal numbers by interpreting the instructions which it is given.

As pointed out before, Floating Point means that the numbers are not represented in the usual machine code which has the point fixed in a certain location but rather in a code which presents the numbers in the form $m \times 10^n$ where m is a decimal integer and n is also a decimal integer giving the power of 10 by which m must be multiplied to produce the original number.

The instructions are coded numbers of the form ϕ xxxx. ϕ is an alphabetic symbol called the operation code and xxxx is the operand address that gives the location of a number on the memory drum. The operation code tells the computer what to do with the number in location xxxx. This Floating Point Interpretative System (H1-24.2) was used in the programing for the solution of the statistical problems in this study.

APPENDIX C

Floating Point (24.2) Mean and Standard Deviation Computer Program

Function: To compute the mean value and the standard deviation for a set of N points, using the Floating Point Interpretative System (H1-24.2) for all calculations.

Operation: After loading the program, transfer to Lo. The program will then call for input data.

Input: The number of points N as an integer, followed by a stop code, followed by the points in standard H1-24.2 format, followed by f'.

Output: Alphameric print of the mean value followed by the standard deviation in the format of the floating point system H1-24.2. After these values have been printed, the program will stop at Lo + 049 on Z0800. A new set of data may be read in by pressing the start button.

Time: Approximately $3 + 4.85\ N$ seconds

Storage: 64 locations are required for instructions and constants. No temporary storage is used except that required by program H1-24.2

Limits: $N \leq 615$

Mean and Standard Deviation Program

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
	0004000'/0004000'		
-0370000'			
0000	b	0054	
1	xc	6300	
2	xp	0045	
3	xi	0000	Input N
4	n	0053	
5	xh	6351	
6	n	0049	
7	c	0055	
8	xu	1919	
9	n	0053	
10	y	0021	Transfer N to 0021
11	y	0030	Transfer N to 0030
12	c	0056	
13	c	0057	
14	xr	6300	24.2
15	xu	0400	
16	i	0100	Input data
17	c	0055	
18	h	0058	N
19	s	0051	
20	h	0060	N-1
21	7c	0000	
22	x7e	0000	set up I. R. #7
23	x71	0002	
24	b	0056	
25	7a	0100	x_1
26	7z	0025	
27	d	0058	x_1/N
28	h	0058	$\bar{x}$
29	x7e	0000	
30	7c	0000	set up I. R. #7

	Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
	0031	7b	0100	
	32	s	0058	
	33	h	0062	
	34	m	0062	$(x_i - \bar{x})^2$
	35	a	0056	
	36	h	0056	
	37	7z	0031	
	38	d	0060	$(x_i - \bar{x})^2/N-1$
	39	xr	0000	
	40	xu	0000	
.0000004'	41	40 m4	34a4	
	42	m4 60	s4t4	
	43	.j d4	34vj	
	44	.j 40	0000	
	45	z	0058	Print out routine
	46	xd	0000	
	47	xz	0020	
	48	xs	0000	
	49	xz	0800	stop
	50	u	0000	
.0000003'	51	4000	0000	1
	52		4	
	53		2	
	54	u	0009	
	55	51	1392	
	56			
	57			x_i, $(x_i - \bar{x})^2$
	58			
	59			N , $\bar{x}$
	60			
	61			N-1
	62			
	63			$(x_i - \bar{x})$
		.0004000'		

APPENDIX D

Floating Point (24.2) Mean, Standard Deviation and Correlation Coefficient Computer Program

Function: To compute the mean values, the standard deviations and the correlation coefficient for a set of 20 pairs of points, using the Floating point Interpretative System (H1-24.2) for all calculations.

Operation: After loading the program, transfer to Lo + 2. The program will then call for input data.

Input: The constants (20 and 19) in successive locations starting at 4410, followed by g', followed by the two sets of 20 points x and y starting at location 5000 in standard H1-24.2 format, followed by f'.

Output: Alphameric point of the mean value followed by the standard deviation of the first set of points, followed by the mean value and standard deviation of the seemed set of points, followed by the correlation coefficient in the format of the floating point system H1-24.2. After these values have been printed, the program will stop at Lo + 359 on ±0800, unless Break Point 8 is depressed. A new set of data may be read in by pressing the start button.

Time: Approximately 7 minutes.

Storage: 4 tracks plus 13 locations are required for instructions and constants. No temporary storage is used except that required by program H1-24.2.

Limits: Only 20 pairs of points can be read in.

Mean, Standard Deviation and Correlation Coefficient Program

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
	;0004000		
4000	r	6300	24.2
1	u	0400	
2	i	0000	Input
3	7c	0020	
4	7e	0000	
5	7i	0002	
6	b	4360	
7	7a	5000	x_i
8	7z	4007	
9	d	4410	x_i/N
10	h	4360	$\bar{x}$
11	7e	0000	
12	7c	0020	
13	7b	5000	
14	s	4360	
15	h	4362	
16	m	4362	$(x_i - \bar{x})^2$
17	a	4400	
18	h	4400	
19	7z	4013	
20	d	4412	$(x_i - \bar{x})^2/N-1$
21	r	0000	x
22	h	4400	
23	7c	0020	
24	7c	0000	
25	7i	0002	
26	b	4404	
27	7a	5040	y_i
28	7z	4027	
29	d	4410	y_i/N
30	h	4404	$\bar{y}$
31	7e	0000	
32	7c	0020	
33	7b	5040	
34	s	4404	
35	h	4362	
36	m	4362	

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
4037	a	4406	$(y_i - \bar{y})^2$
38	h	4406	
39	7z	4033	
40	d	4412	$(y_i - \bar{y})^2/N-1$
41	r	0000	y
42	h	4406	
43	b	5000	
44	s	4360	
45	h	4362	
46	b	5040	Correlation coefficient routine
47	s	4404	
48	h	4402	
49	m	4362	
50	a	4408	
51	h	4408	
52	b	5002	
53	s	4360	
54	h	4362	
55	b	5042	
56	s	4404	
57	h	4402	
58	m	4362	
59	a	4408	
60	h	4408	
61	b	5004	
62	s	4360	
63	h	4362	
4100	b	5044	
1	s	4404	
2	h	4402	
3	m	4362	
4	a	4408	
5	h	4408	
6	b	5006	
7	s	4360	
8	h	4362	
9	b	5046	
10	s	4404	

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
4111	h	4402	
12	m	4362	
13	a	4408	
14	h	4408	
15	b	5008	
16	s	4360	
17	h	4362	
18	b	5048	
19	s	4404	
20	h	4402	
21	m	4362	
22	a	4408	
23	h	4408	
24	b	5010	
25	s	4360	
26	h	4362	
27	b	5050	
28	s	4404	
29	h	4402	
30	m	4362	
31	a	4408	
32	h	4408	
33	b	5012	
34	s	4360	
35	h	4362	
36	b	5052	
37	s	4404	
38	h	4402	
39	m	4362	
40	a	4408	
41	h	4408	
42	b	5014	
43	s	4360	
44	h	4362	
45	b	5054	
46	s	4404	
47	h	4402	
48	m	4362	

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
4149	a	4408	
50	h	4408	
51	b	5016	
52	s	4360	
53	h	4362	
54	b	5056	
55	s	4404	
56	h	4402	
57	m	4362	
58	a	4408	
59	h	4408	
60	b	5018	
61	s	4360	
62	h	4362	
63	b	5058	
4200	s	4404	
1	h	4402	
2	m	4362	
3	a	4408	
4	h	4408	
5	b	5020	
6	s	4360	
7	h	4362	
8	b	5060	
9	s	4404	
10	h	4402	
11	m	4362	
12	a	4408	
13	h	4408	
14	b	5022	
15	s	4360	
16	h	4362	
17	b	5062	
18	s	4404	
19	h	4402	
20	m	4362	
21	a	4408	
22	h	4408	

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
4223	b	5024	
24	s	4360	
25	h	4362	
26	b	5100	
27	s	4404	
28	h	4402	
29	m	4362	
30	a	4408	
31	h	4408	
32	b	5026	
33	s	4360	
34	h	4362	
35	b	5102	
36	s	4404	
37	h	4402	
38	m	4362	
39	a	4408	
40	h	4408	
41	b	5028	
42	s	4360	
43	h	4362	
44	b	5104	
45	s	4404	
46	h	4402	
47	m	4362	
48	a	4408	
49	h	4408	
50	b	5030	
51	s	4360	
52	h	4362	
53	b	5106	
54	s	4404	
55	h	4402	
56	m	4362	
57	a	4408	
58	h	4408	
59	b	5032	
60	s	4360	

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
4261	h	4362	
62	b	5108	
63	s	4404	
4300	h	4402	
1	m	4362	
2	a	4408	
3	h	4408	
4	b	5034	
5	s	4360	
6	h	4362	
7	b	5110	
8	s	4404	
9	h	4402	
10	m	4362	
11	a	4408	
12	h	4408	
13	b	5036	
14	s	4360	
15	h	4362	
16	b	5112	
17	s	4404	
18	h	4402	
19	m	4362	
20	a	4408	
21	h	4408	
22	b	5038	
23	s	4360	
24	h	4362	
25	b	5114	
26	s	4404	
27	h	4402	
28	m	4362	
29	a	4408	
30	h	4408	2 $(x-\bar{x})$ $(y-\bar{y})$
31	b	4412	
32	m	4400	
33	m	4406	
34	h	4402	$(N-1)$ $(\ x)$ $(\ y)$

Instruction Address	Operation Code	Operand Address	Accumulator Contents and Remarks
4335	b	4408	
36	d	4402	$(x-\bar{x})(y-\bar{y})$ /(n-1) (x) (y)
37	h	4408	r
38	u	0000	
39	40m4	e4a4	
40	n460	s4t4	
41	.jd4	e4vj	
42	.j60	m4e4	
43	a4n4	60s4	
44	t4.j	d434	
45	vj.j	60d4	
46	ojr4	r4.j	
47	cr0j	e4f8	
48	.j40	0000	Print out routine
49	z	4360	
50	d	0000	
51	z	4400	
52	d	0000	
53	z	4404	
54	d	0000	
55	z	4406	
56	d	0000	
57	z	4408	
58	m	0000	
59	z	0800	Stop
60			
61			
62			
63			
4400			
1			
2			
3			
4			
5			
6			
7			
8			
4409			
10			N
11			
12			(n-1)
13			
	u	4002	
	.000	4000	